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Modelling noise exposure from roads
– A case study in Burlöv municipality

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Motorväg i Burlöv, foto Burlövs kommun
http://www.burlov.se/omradesmeny/byggabomiljo/bullerochluftkvalitet/luftenutomhus.4.771c1dcc126b1f952f480007415
html

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Abstract

Noise has negative health effects according to a number of studies (Barregård *et al.* 2005; Rosvall *et al.* 2009; Nilsson, Eriksson & Palmqvist 2009). Example of problems that can occur from exposure to noise is sleeping disturbances, heart diseases, lessened learning and reduced cognitive performance (Berglund, Lindvall & Schwela 1999). This kind of problems cause suffering on a personal level and lead to costs for the society.

Burlöv municipality in southwest Scania has some of the most trafficked roads in Sweden and acts as a link between central Europe and the Scandinavian peninsula. The inhabitants in Burlöv are also, according to a compilation of a questionnaire (Albin & Bodin 2010), the persons that experience themselves as most annoyed of noise from roads in all of Scania. Even so former studies show noise levels lower than average in Scania (Simonsson 2009; Appelberg 2009). Is that possible?

The purpose of this study is to model the noise exposure from roads and quantify the number of persons exposed to different levels of noise in Burlöv municipality.

The study was conducted with focus on finding an as detailed method as possible to model noise in Burlöv municipality using Road Traffic Noise - Nordic Prediction Model from 1996 (Jonasson *et al.* 1996) implemented in a software called SoundPLAN (2010).

The results from the noise modelling show that a significant part of the population in Burlöv is exposed to noise levels from roads higher than threshold values and guidelines. During nighttime are more than 6 out of 10 persons in Burlöv exposed to noise levels > 45 dB(A), which is a recommended threshold from the World Health Organization (Berglund, Lindvall & Schwela 1999). Modelled noise levels of L_{den} in this study (51 %) were also higher than modelled levels from road traffic noise in both Gothenburg (43 %; Hammarlund 2007) and Stockholm (34 %; Hallberg, Simonsson & McConnachie 2007), but lower than in Malmö (75 %; Appelberg 2007). This shows that modelled noise levels in Burlöv are in the same size as the three biggest cities in Sweden.

Keywords: Geography, Physical Geography, Noise modelling, GIS, SoundPLAN, Nordic prediction method – Road Traffic Noise

Sammanfattning

Ett antal studier har visat att buller har negativa hälsoeffekter (Barregård *et al.* 2005; Rosvall *et al.* 2009; Nilsson, Eriksson & Palmqvist 2009). Exempel på problem som kan uppstå på grund av buller är sömnsvårigheter, hjärt- och kärlsjukdomar, minskad inlärning och reducerad kognitiv förmåga (Berglund, Lindvall & Schwela 1999). Dessa typer av hälsoproblem leder till lidande för den enskilde individen och till kostnader för samhället i stort.

Burlövs kommun i sydvästra Skåne har några av de mest trafikerade vägarna i Sverige och fungerar som en länk mellan Centraleuropa och den Skandinaviska halvön. Invånarna i Burlöv är också de som upplever sig som mest störda av buller från vägar i Skåne enligt en sammanställning av enkäter (Albin & Bodin 2010). Trots detta så visar tidigare studier att bullernivåerna är lägre än de genomsnittliga i Skåne (Simonsson 2009; Appelberg 2009). Är detta möjligt?

Syftet med denna studie är att modellera bullerexponering från vägar så att antalet personer utsatta för olika bullernivåer i Burlövs kommun kan kvantifieras.

Studien utfördes med fokus på att hitta en så pass detaljerad metod som möjligt för att göra detta genom att använda sig av Nordisk beräkningsmodell för buller från vägar från 1996 (Jonasson *et al.* 1996) som finns implementerad i mjukvaran SoundPLAN (2010).

Resultaten från bullermodelleringen visar att en betydande del av befolkningen i Burlöv är exponerade för bullernivåer från vägar som är högre än de gränsvärden och rekommendationer som finns. Under nattetid är mer än 6 av 10 personer i Burlöv exponerade för bullernivåer > 45 dB(A), vilket är ett rekommenderat gränsvärde från Världshälsoorganisationen (Berglund, Lindvall & Schwela 1999). Modellerade värden av L_{den} i denna studie (51 %) var också högre än modellerade värden från vägtrafik i både Göteborg (43 %; Hammarlund 2007) och Stockholm (34 %; Hallberg, Simonsson & McConnachie 2007), men lägre än i Malmö (75 %; Appelberg 2007). Detta visar att de modellerade bullervärdena i Burlöv är i samma storleksordning som i Sveriges tre största städer.

Nyckelord: Geografi, Naturgeografi, Bullermodellering, GIS, SoundPLAN, Nordisk beräkningsmodell för buller från vägar

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Glossary

ADT	Average daily traffic is the number of vehicles traveling on a road during a day (24 hours).
Amplitude	In longitudinal wave's amplitude describes the rise and fall of pressure and is measured in decibel (dB)
A-weighted	Frequency weighting, where noise that human ears are sensitive to is weighted higher than other noise.
dB	Decibel is a measure that describes the sound pressure levels, e.g. the loudness of sound.
dB(A)	A-weighted decibel, a measure that describes loudness of noise where noise that human ears are sensitive to is weighted higher.
DSM	Digital Terrain Model contains information about elevation of landscapes, including both buildings and vegetation.
DTM	A Digital Surface Model contains information about ground elevation without buildings and vegetation.
Façade noise mapping	Calculation of noise exposure at the façades of buildings.
Frequency	Number of repetitions of a wave per second. The unit is Hertz (Hz).
Grid noise mapping	Calculation of area distribution of noise exposure.
Impedance	Measure to describe the ability of the ground to reflect sound.
L_{Aeq}	A-weighted equivalent sound pressure level.
$L_{Aeq,24h}$	A-weighted equivalent sound pressure level during 24 hours, this means the mean value during 24 h. It is representative for a yearly average day.
$L_{AF\max}$	A-weighted maximum noise pressure level during 0,125 seconds.
L_{den}	A-weighted equivalent sound pressure level during 24 hours, where evening levels (18.00-22.00) gets a 5 dB(A) penalty and night levels (22.00-06.00) gets a 10 dB(A) penalty.
L_{night}	A-weighted equivalent sound pressure level during the night (22.00-06.00).
Receiver	The point of calculation, when calculating noise exposure.

Search radius	A given radius from the receiver within which all sources of noise are included in the calculation of noise exposure.
Sound pressure level	Effective sound level in comparison to the threshold of human hearing 0 dB(A). The unit is dB(A).
Source	In noise mapping it is something that emits noise, in this study the source is a road.

1. Introduction

1.1 Background

Several studies have shown that noise affects humans in a negative way (Barregård *et al.* 2005; Rosvall *et al.* 2009; Nilsson, Eriksson & Palmqvist 2009). Examples of problems that can occur from exposure to noise are sleeping disturbances, heart diseases, lessened learning and reduced cognitive performances (Berglund, Lindvall & Schwela 1999). These kinds of problems cause suffering and lead to costs for the society, which has brought noise disturbances to become more and more acknowledged as the knowledge about the issue has increased.

Noise originates from several sources. One large source is transportation and since population numbers are increasing and we have a tendency to live closer to each other today than before, the number of people living close to infrastructure increases and by that also the number of exposed to noise from transportation (Santamato 2009).

In 2002 the European Union (EU) issued a directive called the Environmental Noise Directive (the END-directive) for governing noise exposure with the purpose to implement common methods and measures within the EU when handling noise exposure (2002/49/EG). The END-directive was implemented in the Swedish legislation in the code of statues (SFS: 2004:675). The directive both stated threshold values of noise exposure and methods to use when modelling noise exposure (2002/49/EG).

In 2006 the number of persons in Sweden exposed to noise originating from transportation, and being above the threshold value, were about 2 million (Simonsson 2009). The number of persons exposed to noise originating from roads and being above the threshold was about 1.73 millions. These numbers show that noise from road traffic is the largest contributor to the overall noise disturbance coming from transportation in Sweden. In the same report, the percentage of the population in Scania exposed to noise from roads above the threshold was 18 % (Simonsson 2009 in Albin & Bodin 2010).

Noise has an ability to vary through time and space, which makes average noise exposures over longer time periods hard to measure. Measurements only represent the moment or period it is registered, which means that it is both time and money consuming to determine average noise exposures of a certain site based on measurements. Therefore, models are often used when mapping noise exposure. The Road Traffic Noise - Nordic Prediction Method (RTN) from 1996 is a common method used in the Nordic countries to predict and map noise exposures through modelling (Jonasson *et al.* 1996). The method fulfills the demands of the END-directive from the EU and of Swedish legislation.

Burlöv municipality in southwest Scania is a relatively small area with a high density of infrastructure. Large parts of the traffic from Denmark and the continent passes, via the Öresund's bridge, through Burlöv on its way up to the Scandinavian peninsula and the other way around. Large parts of the population in Burlöv are also concentrated close to larger roads.

The experienced disturbance of noise in Burlöv is the highest in Scania, but so far estimations and models have shown a relatively low exposure to noise in the same area (Albin & Bodin, 2010).

1.2 Purpose and target group

The purpose of this study is to model the noise exposure from road traffic in Burlöv municipality and to quantify the number of persons exposed to different levels of noise.

To be able to fulfill this purpose the following questions need to be answered:

- How is noise modelled and what factors are important for noise propagation?
- In what way is consideration paid to important factors and how important are they when quantifying noise?
- What kind of uncertainty exists in the quantification of noise and how does it affect the results?

The target group in this study is researches and students within the field of noise exposure, employees and decision makers at municipalities (especially Burlöv municipality) and the faculty of Medicine at Lund University.

2. Theory

2.1 What is sound?

If something is moving back and forth, up and down, side to side or in and out that thing can be said to be vibrating. A vibration that has a spatial propagation is a wave. Sound is a kind of wave that travels through solid, liquid or gaseous materials that are elastic and therefore it does not have the ability to travel trough vacuum.

There are two different types of waves: transverse and longitudinal waves. Transverse waves are waves that have a transverse motion like waves on the water or waves created when you tie a rope on a pole at one end and move the other end up and down (Figure 1). In transverse waves the motion of the wave is at a right angle to the direction of the wave. It can be described as the type of wave that you usually think of when thinking of a wave.

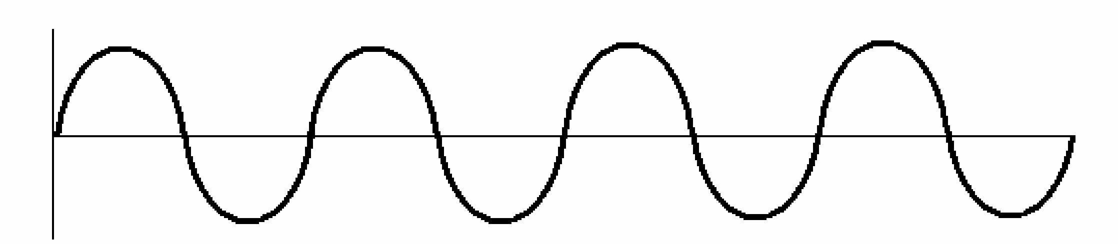

Figure 1: The wave motion in a transverse wave, such as an ocean wave, moves perpendicular to its direction.

Longitudinal waves are waves where the motion of the wave is along the direction of the wave instead of at a right angle to it. The medium is compressed and decompressed. Figure 2 describes a longitudinal wave. One example of a longitudinal wave is sound. It is for example created when we speak, through motions in the vocal chords.

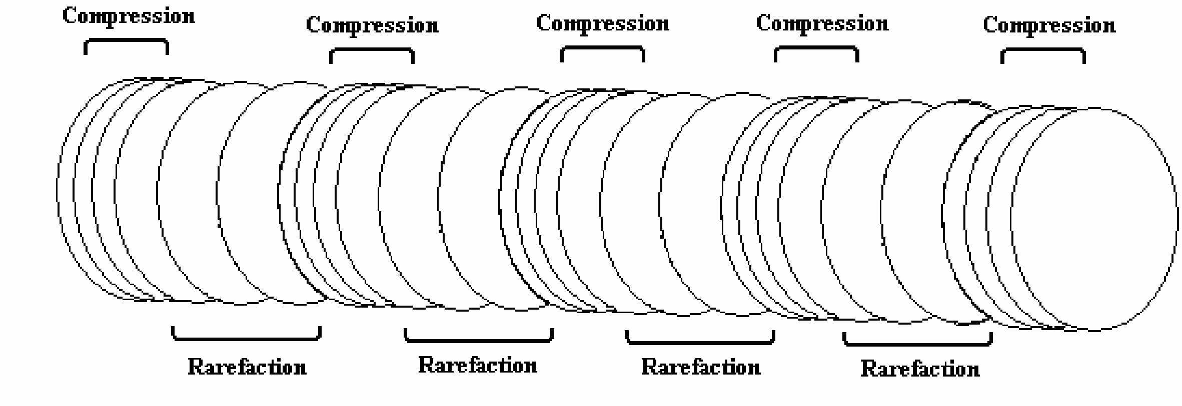

Figure 2: The wave motion in a longitudinal wave is along the direction of the wave. The medium in which the wave is traveling is compressed and decompressed.

Sound can be produced in several different ways (Rossing 2007). It can be produced by for example:

- A vibrating body. Earthquakes, a violin string or the friction of the tires of a car can produce sound. The motion of the object causes the local air pressure to fluctuate, which creates the sound.
- Changing airflow. When we speak the air is released in puffs through motions of our vocal chords, which creates a sound.
- A time-dependent heat source. An electrical spark or an explosion such as a lightning or an explosion creates sound due to expansion of air caused by rapid heating.
- Supersonic flow. When something, for example an airplane, travels faster than the speed of sound and forces the air to do the same. Sound is created through a supersonic flow.

(Section 2.1 What is sound is based on Fahy 2003; Hewitt 2006 and Rossing 2007)

2.2 Perception of Sound

The perception of sound starts in the outer ear (Figure 3). The outer ear works as a funnel, which collects and directs the sound towards the eardrum (Passer *et al.* 2009). Sound then reaches the eardrum and causes it to vibrate. These vibrations transfer the sound energy from the outer ear to the middle ear. The middle ear contains three small bones: the hammer, the anvil and the stirrup. These bones work as a safety level between the sensible inner ear and the outer ear. The bones reduce the energy in the sound and direct it, via vibrations, to the inner ear. In the inner ear the sound energy is transformed into electrical impulses, via chemical substances and through the stimuli of small hair cells in the Cochlea, a snail-shaped tube organ in the inner ear. These electrical impulses are then transferred via the auditory nerve to the brain, where the sound is finally registered.

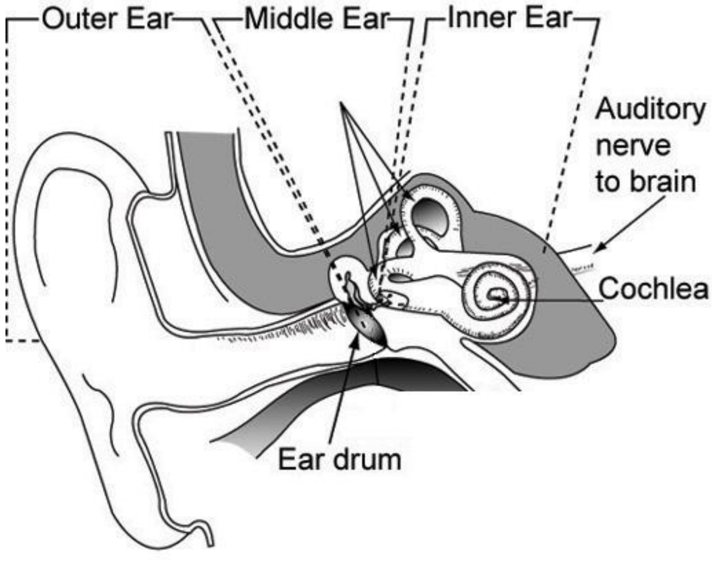

Figure 3: Sound travels from the outer ear to the inner ear via the middle ear. In the inner ear is the sound is transformed to electrical impulses, which are transferred to the brain via the auditory nerve (NASA 2010).

A sound wave is described by frequency and amplitude. Frequency describes the number of sound waves during a second and is measured in Hertz. Humans have the ability to percept sound waves from 20 to 20000 Hertz. The higher frequency the wave has the higher is the perceived pitch from the sound. Therefore a low frequency produces a dark sound and a high frequency a lighter one. The ability to intercept higher frequencies usually lessens with age.

Amplitude describes the distance between the compression and rarefaction in the sound wave. This describes the physical pressure at the eardrum and is expressed in decibel (dB). A logarithmic scale measures sound. This means that a sound level is not increased by the double when two equally large sources are contributing. Instead the sound level is increased by 3 dB. Even so the loudness of sound is experienced as double if the sound level increases by 8-10 dB (Hammarqvist, Tholen & Odebrant 2003). A-weighted decibel (dB(A)), is a measure that describes loudness of noise where noise that human ears are sensitive to is weighted higher.

A popular way of illustrating sound levels from different sources is with a decibel scale (Figure 4).

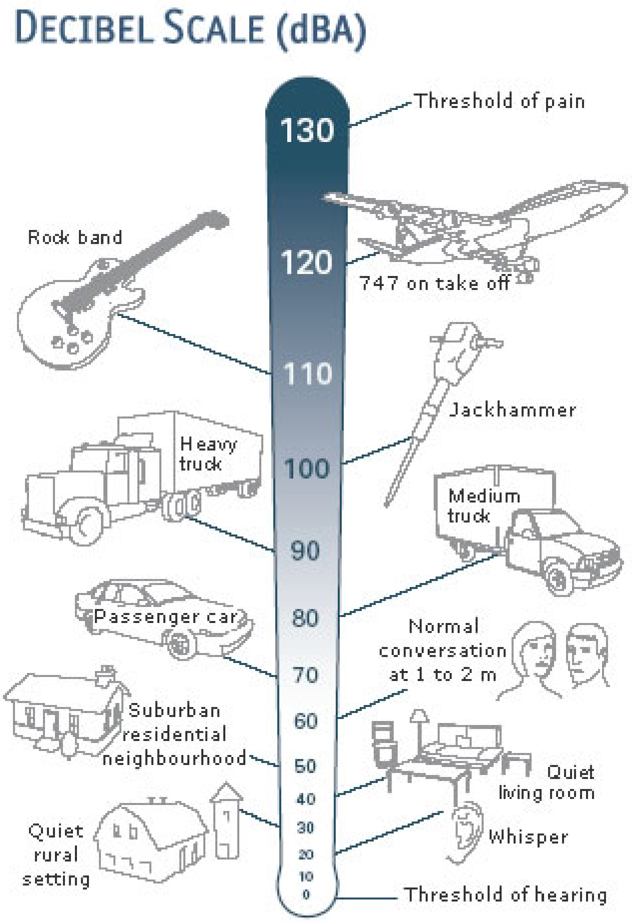

Figure 4: Sound level varies between different sources. The decibel scale is logarithmic, which means that two equally large sources increase the noise level with 3 dB(A) (Soundsmart 2010, page 4).

Noise from cars decrease with about 4 dB(A) in sound pressure level when the velocity decreases from 70 km/h to 50 km/h. While a decrease from 50 km/h to 30 km/h decreases the sound pressure level with about 2 dB(A) (Appelberg 2010).

2.3 Sound Propagation

The propagation of sound is a complex science. There are several things that govern how sound travels from a source that creates the sound to a receiver that intercepts it.

As mentioned earlier, sound needs a medium to travel through. This medium can for example be air, water or soil. It is not the medium itself that is moving, but the energy in the wave. The speed of sound is dependent on the type of medium that it is travelling through. Sound travels faster in solid materials like iron and water than in air. This is because in solid materials the molecules are more closely linked and thereby they faster transmit waves, and with a lower cost of energy. The speed of sound in air is also variable; for example it depends on water saturation and temperature of the air. A higher level of saturation or temperature in the air means higher speed of the sound.

Sounds from smaller *source*s, such as cars, are often estimated as point *source*s. The propagation from a point *source* is spherical if the sound travels undisturbed (Figure 5). Obstacles like buildings act as screens when noise propagates.

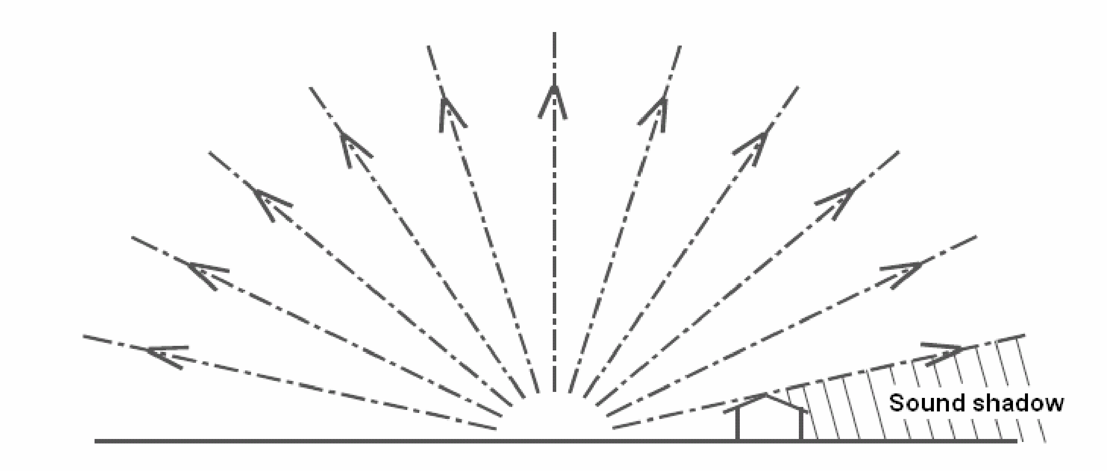

Figure 5: Sound propagates spherically from a point source (Hammarqvist et al., 2003).

Differences in temperature and saturation lead to what is called refraction of the sound. Refraction of sound occurs when the front of a sound is travelling in a different speed than the back of a sound wave, which can lead to bending of the sound. This is an important phenomenon when studying the effects of weather on sound propagation. If air close to the ground surface is warm, with a decrease of temperature with increasing distance to the ground, the sound will bend away from the ground. On the other hand if the temperature is cold close to the ground and increase with distance from the ground, the sound will bend towards the ground. According to a study made on noise from railroads in Åkarp inversion in the atmosphere, created by temperature differences, is more important to the spreading of sound than the elevation of the terrain is (Mattsson *et al*. 2009).

Wind speed and direction also affects the propagation of sound. If sound is propagating in the same direction as the wind the sound will bend downward and if it is propagating in the opposite direction it will bend upwards (Figure 6).

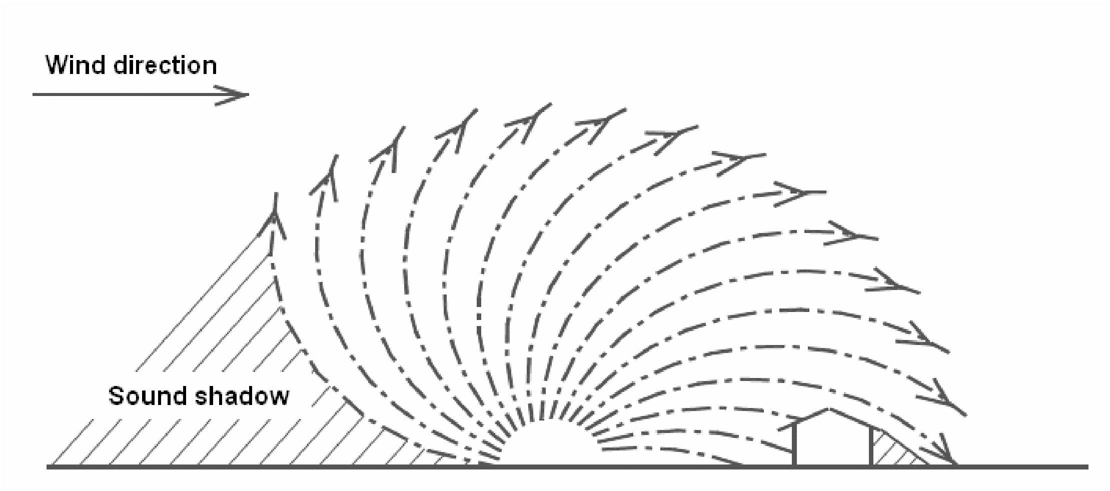

Figure 6: Sound propagation in wind (Hammarqvist et al., 2003).

When it comes to the reflection of sound, what you see is what you hear. That means that if you can see the *source* of the sound you can also hear it. This principle is used in for example concert halls to direct the sound towards the audience. In Davies Hall in San Francisco they have plastic plates in the roof that work as reflectors. The plates also work as mirrors, which makes it is easy to direct the sound to a wanted spot.

(Section 2.3 Sound propagation is based on Fahy 2003, Hewitt 2006 and Rossing 2007)

2.4 What is noise?

There are a number of ways to define noise. According to a physical definition noise is an irregular sound wave in comparison to regular sound waves, that are not. Even so it is hard to tell between what noise is and is not. Noise can be said to be subjective.

According to the Swedish national encyclopaedia (2010) noise is an unwanted, sound pollution that sometimes can be damaging to the hearing. Noise is often caused as a by-product from mechanical equipment. Similar to this definition is the definition of surrounding noise from the EU (2002/49/EG), which is also the definition used in this study:

"Unwanted or damaging outdoor sound that is caused by human activity, including noise from transportation, road traffic, railroad traffic, air traffic and areas with industrial activity…." (Translated from 2002/49/EG by Mattisson)

2.4.1 Injuries caused by noise

According to the national board of health and welfare noise can injure humans ability to hear, it can cause sleep disturbances, decrease learning abilities and it can also increase the risk of heart and vessel diseases (Nilsson & Eriksson 2009). The magnitude of damage is strongly related to noise level and time of exposure, but also to the character of the noise.

Hearing damages vary by type and can be caused by the environment, for example by noise, but they may also be hereditary. The most common problem is impaired ability to hear certain frequencies and they derive from damages in the inner ear, for example in the cochlea or on nerves going from the cochlea. These types of damages cannot be cured by medicine or surgery (Hörselskadades riksförbund 2010).

In a study from 2007 (Persson *et al.*) annoyances from different sources of noise and air pollution were compared, such as sounds from neighbors, vibrations from traffic, smells from industrial production and industrial noise. The most annoying source from this study was traffic noise, which was experienced by 8.3% of the 2847 persons included in the study. The noise exposure from roads of the participating persons was mapped based on a simplified version of the Road traffic noise – Nordic prediction method (RTN; Jonasson *et al.* 1996) (explained under 2.6.1) and was shown to be positively related to traffic noise annoyance.

That noise from roads increases the risks of myocardial infarction (heart attack) was shown in a study by Selander *et al.* (2009). As in the previously mentioned study, noise exposure was also here calculated according to a simplified version of the RTN (Jonasson *et al.* 1996). Selander *et al.* (2009) found that persons exposed to levels of 50 dB(A) or higher since 1970 tend to have a higher risk of getting heart attacks than persons exposed to levels below 50 dB(A). They also found that the risk of heart attacks was especially high for persons who were disturbed by noise during their sleep. Several other studies have also shown relation between exposure to noise and increased risk for heart related diseases (Babisch *et al.* 2005; Barregård *et al.* 2005; Bluhm *et al.* 2007)

2.5 Quantification of noise exposure

Noise can be quantified both by measurements and modelling; both methods have their strengths and weaknesses. When measuring noise levels the actual noise level at the time of measurement is quantified, this gives the real noise level at the moment of quantification. If a noise level only needs to be quantified for one point source or over a small area noise measurement is a good method to quantify noise. But if noise levels need to be quantified over larger areas this method presents practical problems. One major issue is that since noise fluctuates widely over time and space a large number of measuring points with continuous measuring would be needed in order to quantify the average noise level in an area. Measuring noise therefore often is very time consuming (Bendtsen 1999). While noise varies strongly depending on time it is preferable to represent it as an average over for example a day or a year. It would be very costly to measure constantly over a year; modelling noise is in this perspective therefore preferable. Another source of error is that it is very important that the same procedure is used when measuring noise, for example the same height, if not the measures might not be comparable.

Because of, amongst others, the reasons mentioned above, a more practical way of representing average noise over large areas and longer time-scales is to model the noise. There are several calculation methods that can be used when calculating the propagation of noise, but in order to be able to compare results from different noise mappings it is preferable to use one common method.

2.5.1 Measures to describe noise

Noise measures describe the level of noise exposure. There are a number of measures that can be used to describe different kind of exposures.

L_{Aeq} = Describes the A-weighted equivalent continuous sound pressure level during a certain time period (Jonasson *et al.* 1996). In an A-weighted measure the middle part of the human sound spectrum is weighted higher than low and high frequencies since these frequencies are better intercepted by the human ear.

$L_{Aeq,24h}$ = Describes the A-weighted equivalent continuous sound pressure level during 24 hours (Jonasson *et al.* 1996). This is the average sound pressure level during a 24 hour period and it represents a day year average.

L_{night} = It is also possible to calculate the equivalent sound pressure level for different time periods. L_{night} describes the A-weighted equivalent continuous sound pressure level during 8 hours in the night time, usually between 22.00-06.00 hours.

L_{day} = A-weighted equivalent continuous sound pressure level during 12 hours in the day, usually between 06.00-18.00 hours.

$L_{evening}$ = A-weighted equivalent continuous sound pressure level during 4 hours in the evening, usually between 18.00-22.00 hours.

$L_{AF\max}$ = The maximum sound pressure level from a source, that is both A-weighted and F-weighted. F-weighted means that the maximum noise is measured during 125 ms, this gives the maximum exposure level from the source (Berglund, Lindvall & Nilsson 2002).

L_{den}= A measure from the European Union that has its origin in $L_{Aeq,24h}$. It also describes the A-weighted equivalent continuous sound pressure level during 24 hours with the difference that evening and night exposure gets a penalty (Berglund, Lindvall &Nilsson 2002). Noise in the evening (18.00-22.00 hours) gets a 5 dB(A) penalty and noise in the night (22.00-08.00 hours) gets a ten 10 dB(A) penalty. Otherwise L_{den} is calculated as $L_{Aeq,24h}$.

All measures are expressed in the unit A-weighted decibel (dB(A)).

2.6 Modelling Noise from Roads

For some time there has been collaboration between the Nordic countries (Nordic Council 2010) in finding a method to harmonize the way of modelling noise from roads. In 1978 the first version of a harmonized method that described how to model noise from roads was published. The second version was published in 1989, the third version was published in 1996 (Jonasson *et al.* 1996) and a fourth version was published in 2001 (Jonasson & Storeheir 2001). The method that is used in this study is the method from 1996.

There is also ongoing work within the EU called Harmonoise, which aims at finding a method that can be used by all member states. Thereby it would be possible to compare results between different countries (de Vous, Beuving &Verheijen 2005).

2.6.1 Road Traffic Noise - Nordic Prediction Method

The RTN is a method that predicts noise emitted from roads (Jonasson *et al.* 1996). Noise levels are primary calculated in L_{Aeq} and $L_{AF\max}$, based on L_{Aeq} they can also calculate for example L_{den} and L_{night}. The mathematical models for calculate both L_{Aeq} and $L_{AF\max}$ are similar, and the largest difference between them lies in the distance correction. Only the mathematical model for L_{Aeq} will be presented in this report, for a detailed description of $L_{AF\max}$ see Jonasson *et al.* (1996).

In these models vehicles that travels on the roads emits the noise. The noise level, which is measured in decibel, depends on the number and type of vehicles that travel on the road. With the method it is possible to calculate noise levels for receivers including sources within different distance. Receivers are calculation points for which the noise exposure is calculated.

The general steps to calculate the noise level for L_{Aeq} for a single source is described by equation 1 (Jonasson *et al*. 1996):

$$L_{Aeq} = L_1 + \Delta L_2 + \Delta L_3 + \Delta L_4 + \Delta L_5 \qquad \text{(Equation 1)}$$

where L_{Aeq} = A-weighted equivalent sound pressure level

L_1 = Basic noise level (step 1)

ΔL_2 = Distance correction (step 2)

ΔL_3 = Ground and screen correction (step 3)

ΔL_4 = Other corrections (step 4)

ΔL_5 = Façade correction (step 5)

Equation 1 describes the different steps that need to be calculated. However before these five steps can be calculated the road needs to be divided into sections, depending on differences in sound propagation between the road and the receiver (Figure 7). This needs to be done because sound propagation is not the same along the road and the road is not an infinite straight line. For each of the road segments the five steps of calculations needs to be carried out. When all calculations are made the result from the different road segments will contribute to the noise level.

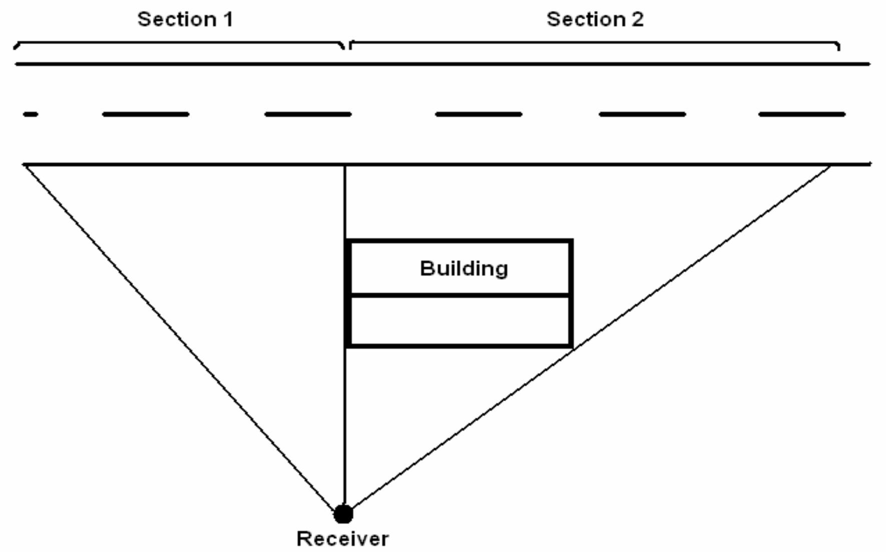

Figure 7: When describing noise level at a receiver roads are divided into segments based on differences in sound propagation between the road and the receiver. In this case the road needs to be divided into two segments and two different calculations need to be performed in order to describe the noise level at the receiver coming from the road.

Step 1 - Basic noise level

Basic noise level is the emitted noise from a source. Roads are sources in this model, even so it is the vehicles passing by on the road that emits the noise not the road itself. To be able to calculate the basic noise level emitted form a road segment there are three input variables that need to be known, apart from the spatial spread of the road:

- The number of heavy vehicles travelling on the road during a 24h hour period
- The number of light vehicles travelling on the road during a 24h hour period
- The real speed (measured average speed) or posted speed of the vehicles (km/h)

Step 2 - Distance correction

Step two is to calculate correction according to the distance. Sound from a source limited in size is spread over an area. When the distance from a source is increased, the area that sounds spreads to also increases. The geometrical spread of the sound is said to be cylindrical and the sound intensity will decrease with 3dB per doubling of distance. Over long distances the height difference between the road and the source can be assumed to be negligible. This is not the case for shorter distances where it is important to correct for the height distance. When assuming a source height of 0,5 m above the road surface the distance correction can be calculated with equation 2:

$$\Delta L_2 = \quad -10\lg\left[\frac{\sqrt{a^2} + (h_m - h_b - 0{,}5)^2}{10}\right] \qquad \text{(Equation 2)}$$

a = Distance from the source to the receiver in meters (m)

h_m = Height of the receiver (m)

h_b = Height of the sources (m)

The heights h_m and h_b are calculated from the same horizontal plane. Basic elements of the formula are illustrated in Figure 8.

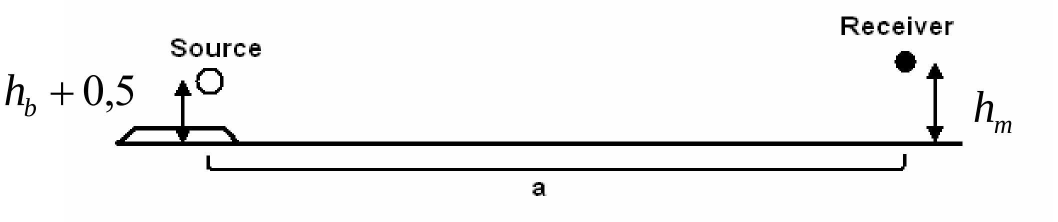

Figure 8: The basic elements when calculating the distance correction in the Road Traffic Noise – Nordic Prediction Method. The height of the source is calculated from a plane of reflection, where 0,5 m is added to the height of the source. The height of the receiver is calculated from the same reference plane. The distance between the two is the Euclidean distance along the reference plan (Jonasson *et al.* 1996).

Step 3 - Ground and screen correction

The third step is to calculate the ground and screen correction. Ground and screen correction is defined as all attenuation in excess of distance attenuation. It refers to parameters such as the noise spectrum of a sound, the height of a sound source above a road surface, the height of a road surface in relation to the ground, the acoustic properties of the ground, the height of a receiver in relation to the road surface and to the ground, screening and weather conditions. It is rather complicated to take all these factors into account and a simplification is therefore made in the model. This simplification only takes these parameters into consideration: height of the road surface above ground, height and position of screens, height of receiver and ground type. The correction in the calculation method differs between if sound is reflected on hard ground, such as asphalt, or on soft ground, such as grass.

Step 4 - Other corrections

In the fourth step of equation 1 step corrections that have not been included in step 1-3 are made. These other corrections are divided in a number of factors that can be corrected and that can be explained by equation 3:

$$\Delta L_0 = \Delta L_\alpha + \Delta L_{ts} + \Delta L_{st} + \Delta L_{ka} + \Delta L_r + \Delta L_{mg} + \Delta L_{ms} + \Delta L_g + \Delta L_b \qquad \text{(Equation 3)}$$

ΔL_0=Other correction (dB(A))

ΔL_α = Correction for angle of view

ΔL_{ts} = Correction for thick screen

ΔL_{st} = Correction for road gradient

ΔL_{ka} = Correction for short distance to the road

ΔL_r = Correction for reflection from a single surface

ΔL_{mg} = Correction for multiple reflections between buildings

ΔL_{ms} = Correction for multiple reflections in side streets

ΔL_g = Correction for multiple reflections in court yards

ΔL_b = Correction for screening and scattering among detached houses

See Jonasson *et al.* (1996) for more details.

Step 5 - Façade correction

Façade correction is used to calculate indoor noise levels. A detailed presentation of façade correction is not given in this thesis because here outdoors levels were calculated. For more information read Jonasson *et al.* (1996).

Total noise level in a receiver is finally calculated through the addition of noise from different road segments. This is done based on an increase of 3 dB(A) with two equally large contributing road segments. Contributions from two road segments decrease logarithmically with increasing difference in sound pressure level between the two sources. If more than two road segments are contributing to one receiver the contribution to the total noise level is added for one road segment at a time (Jonasson *et al.* 1996).

2.6.2 Nord 2000 - New Nordic prediction method for road traffic noise

Nord 2000 (Jonasson & Storeheir 2001) is a method that has been developed from the former Nordic prediction method from 1996. The aim of this method was:

"To develop methods physically correct to the largest possible extent and with a complete separation between source emission and sound propagation" (Jonasson & Storeheir 2001, page 7)

Another aim was to develop a method that is suitable for use in large-scale analysis. The new method has aimed at calculating the noise as accurate as possible and not to compromise with the accuracy for the sake of simplicity. Since the method has many variables it is also possible, and probable, that there will not be data for all parameters. Default values for some parameters are therefore set according to Jonasson and Storeheir (2001).

2.7 Political policies, recommendations and thresholds

2.7.1 World Health Organization

According to the World Health Organization (WHO) it is important not only to calculate average noise level during a day L_{Aeq} but also to calculate maximum levels L_{AFMax}. It is also important to calculate noise levels for certain time period such as day, evening and night. Especially nighttime values are important to calculate because it is important to be able to sleep without disturbances from noise. Different places in the society should also have different noise limits. Some places are especially sensitive such as hospitals, schools and living areas (Berglund, Lindvall & Schwela 1999).

Noise exposure outdoors in residential areas causes serious annoyance when it exceeds L_{Aeq} 55 dB(A) and moderate annoyance at L_{Aeq} 50 dB(A) (Berglund, Lindvall & Schwela 1999). WHO suggest both indoor and outdoor limits for some places such as bedrooms were equivalent night levels should not exceed 30dB(A) indoors and 45dB(A) outdoors. Maximum noise levels outside bedrooms should not exceed L_{AFMax} 60 dB(A). A list of all limits proposed can be found in Guidelines for community noise from WHO (Berglund, Lindvall & Schwela 1999). In a later report, that yet has not had a large impact in Sweden, WHO recommends that equivalent night levels should not be > 40 dB(A), based on studied health affects (Hurtley 2009).

2.7.2 European Union

The END-directive governs noise measurements in Europe (2002/24/EG). The purpose of this directive is to synchronize methods and measures in Europe so that results from noise modelling from different regions and countries can be compared to each other. The directive also aims at making it easier to take common measures against high noise exposure within Europe. The selected measures to represent the noise exposure is L_{den} and L_{night}. The directive contains information about which method to use, threshold values, how results from noise modelling should be presented and were to make noise evaluation. Already existing national methods are allowed to be kept as long as they are adapted to the guidelines in the directive.

The directive states that results should be presented for both the number of exposed persons and for the area distribution of noise exposure, using both L_{den} and L_{night}. However, complementary measures are also allowed (2002/24/EG).

2.7.3 Sweden

Threshold values for noise in Sweden are stated in the infrastructure government bill (Proposition 1996/97:53). In their residences, people should not be exposed to noise levels higher than the threshold values below. Levels are applied to L_{Aeq} and $L_{AF\max}$ and should be reached 2020.

- 30 dB(A) equivalent sound pressure level indoors (L_{Aeq24})
- 45 dB(A) maximum sound pressure level indoors at night ($L_{AF\max}$)
- 55 dB(A) equivalent sound pressure level outdoors (at façade) (L_{Aeq24})
- 70 dB(A) maximum sound pressure level in the yard in connection to the residence ($L_{AF\max}$)

The END-directive (2002/49/EG) has been implemented into the Swedish law (SFS: 2004:675). The noise measures that should be used according to the regulation about surrounding noise 9§ (SFS: 2004:675) in Swedish legislation is L_{den} and L_{night}. Even so threshold values from the government are given in L_{Aeq} (Proposition 1996/97:53).

Noise is mentioned at several places in the Swedish environmental goals by a government bill from 1997 (1997/98:145). It can negatively affect nature experiences and should for example be considered when planning for placement of windmills or roads. Noise should be reduced in population centers, especially noise coming from roads that are big contributors. When planning for traffic, high levels of noise should be reduced with, for example, noise walls (Proposition 1997/98:145).

Three government authorities that are involved in handling noise from roads in Sweden are: the Swedish Environment Protection Agency (Swedish EPA), the Swedish Transport Administration (Swedish TA) and the Swedish Board of Health and Welfare (Swedish BHW). These authorities have different areas of responsibilities and different views on how to handle noise.

The Swedish Environmental Protection Agency (Naturvårdsverket)
The Swedish EPA has a collaborative role in handling noise pollutions. It has the responsibility to guide how Swedish environmental laws, which include noise, will be applied. Every fourth year the Swedish EPA evaluates the number of persons exposed to noise levels above threshold values from roads (Barregård *et al.* 2005).

The Swedish Road Administration (Trafikverket)
The Swedish TA is the authority in Sweden responsible for managing governmental roads, which is larger roads, in Sweden. They are also responsible for making directions of how to build roads and see to that these directions are upheld (Strömmer 2007). When working with noise pollution The Swedish TA has focused on reducing noise levels to the most exposed. This is done for example through construction of noise banks or through different façades measures like changing windows. Another type of measure is to use a road surface that reduces noise emitted by vehicles driving on the road (Strömmer 2007).The Swedish TA also has the responsibility to support work done to reduce too high noise levels on non-governmental roads (Strömmer 2007).

The Swedish Board of Health and Welfare (Socialstyrelsen)
The Swedish BHW has given a recommendation that the equivalent noise levels inside residential buildings should not be higher than 30 dB and the maximum levels should not be higher than 45 dB (SOSFS 2005:6).

2.8 Historical and recent noise exposure from roads

Many studies have been performed in order to quantify the number of persons exposed to noise from roads. According to Simonsson (2009), made on commission from the Swedish EPA, 1.73 million persons in Sweden where exposed to noise levels over 55 dB(A) in 2006. This is an increase from year 2000 when the number of exposed, in the same report, was estimated to be 1.34 million. A prior study made by the Swedish EPA showed that the number of exposed to noise levels above L_{Aeq24} 55 dB(A) was about 1.46 million or about 16 % of the Swedish population in 2000 (Odebrant 2002) This was an increase from 1992 where 1.3 million persons were exposed (Wittmark 1992) and from 1995 when 1.45 million were exposed (Wittmark 1995). When uncertainties in the investigations are taken into consideration however, conclusions about if the number of exposed persons has increased are hard to make (Odebrant 2002).

Simonsson (2009) concludes that 18 % of the population in Scania is exposed to noise levels over L_{Aeq24} 55 dB(A) from roads year 2006, based on modelling. This is the same figure found in a former study, but here concerning year 2000 (Albin *et al.* 2003). Björk *et al.* (2006) estimated that 29% of the population in Scania were exposed to levels over L_{Aeq24} 55 dB(A) and 37% were exposed to maximum levels ($L_{AF\max}$) over 70 dB(A) from road traffic alone.

According to the END-directive (2002/49/EG) noise levels emitted by roads should be calculated for all cities with more than 250 000 citizens and for all roads with more than 6 million vehicles per year. In Sweden this includes cities of Malmö, Göteborg, Stockholm as well as large roads governed by The Swedish TA. Malmö is the city that has got the highest percentage of persons exposed to above recommended noise levels when compared to the EU measure L_{den}. In Malmö, the number of persons exposed to noise levels above 55 dB(A) L_{den} was 212 500 persons, or 75% of the total population in 2006. Noticeable in the study was that all noise values was overestimated with 3 dB(A) (Appelberg 2007). The number of persons exposed to night levels above 55 dB(A) was 97 100, or 34.4% of the total population (Appelberg 2007). The number of persons exposed to L_{den} over 55 dB(A) in Göteborg was 271 400 persons, or 43% of the total population. The number of persons exposed to night levels over 55 dB(A) was 52 080, or 9.5% of the population (Hammarlund 2007). Stockholm was the city with the lowest percentage of population exposed to over threshold values with 271 400 persons, or 34% of the total population, exposed to values above 55 dB(A) L_{den} and 78 200 persons or 9.7% of the total population exposed to night levels above 55 dB(A) (Hallberg, Simonsson & McConnachie 2007).

2.8.1 Burlöv

The number of people exposed to noise levels above 55 dB(A) in Burlöv's municipality varies between different studies. Simonsson (2009) found that the percentage of population exposed to levels above 55 dB(A) in Burlöv's municipality in the year 2006 was 15.5 %. In yet another investigation from 2009, Soundcon estimated the percentage of exposed to be 4% in Burlöv (Appelberg 2009).

These estimates of noise exposure are low compared to the experienced levels in the municipality. In a study concerning experiencing disturbances from road noise in Burlöv 2008, 35.6 % of the population experienced disturbance every week (Albin & Bodin, 2010). Of these 24.2 % experienced disturbance every day.

3. Data and Material

3.1 Area of investigation – Burlöv Municipality

Burlöv's municipality is situated in southwest Scania, in the Öresund region (Figure 9). The Öresund region consists of Scania and parts of Denmark and it is the most densely populated city region in the Nordic countries (Christiansson 2008). The area of Burlöv's municipality is about 19 km^2, which makes it the second smallest municipality out of Sweden´s 290 municipalities In 2009 Burlöv had a population of 16509 inhabitants, with an approximately equal gender distribution (Statistiska centralbyrån 2010). The population is mainly distributed amongst the three population centers Arlöv, Åkarp and Burlöv Egnahem. All three population centers are located between larger roads (Figure 9). Except for the population centers, Burlöv's municipality mainly consists of open farmlands.

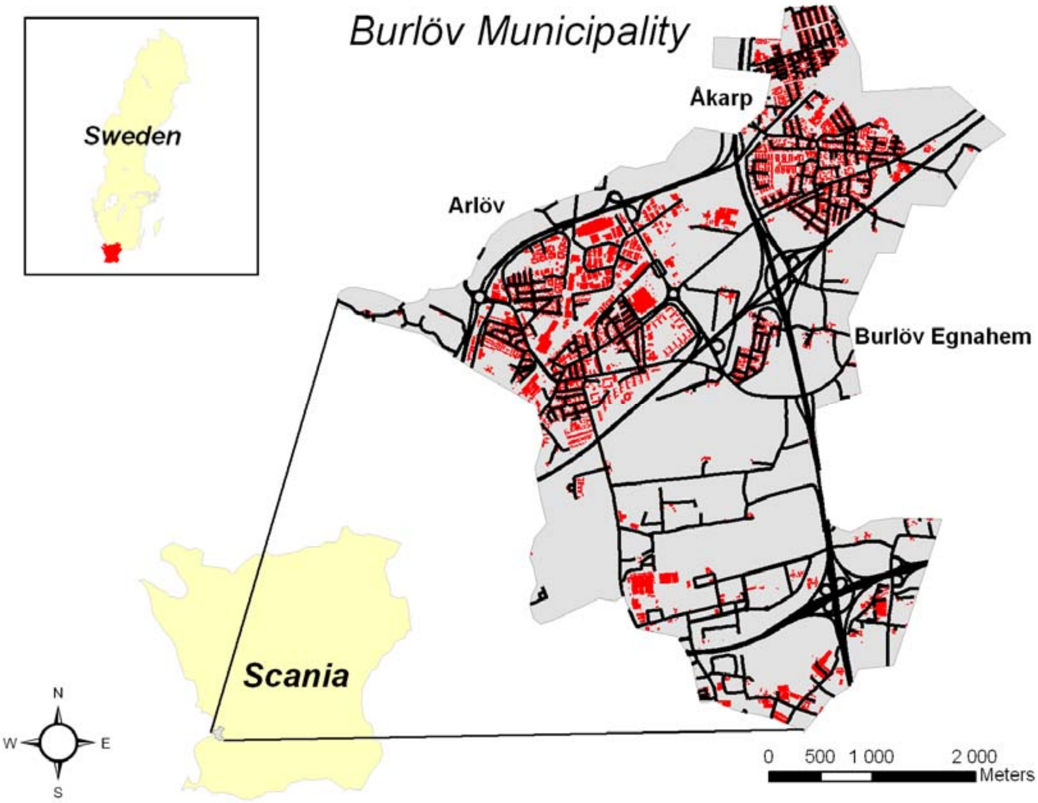

Figure 9: Overview map over Burlöv's municipality and its location in the county of Scania and in Sweden. The map includes population centers and roads.

A substantial part of the road traffic from Europe coming from Copenhagen and entering Malmö and the rest of Sweden by the Öresund Bridge passes through Burlöv. Burlöv is also situated between Malmö and Lund, two cities many people commute between, which results in a large number of vehicles passing through Burlöv's municipality daily.

Temperature conditions in Burlöv are special since Burlöv is situated in a topographic depression. This depression causes cold air to flow down from the surroundings, causing a temperature inversion in the atmosphere. The temperature inversion in turn makes sound waves to bend and increases the noise level in the area a couple of times each month (Mattsson 2009).

3.2 Data

The data used in this study originates from different sources (Appendix A). The list below gives an overview of the data included in the study:

- Road data
- Building data
- Laser elevation data
- Land cover data
- Noise walls data
- Population data
- Satellite elevation data (only included in the sensitivity analysis)

Road data

Road data used in the study originates from the Scania Air Protection Union (SAPU), which is a non-profitable association in collaboration between both private organizations and the public sector (Skånes Luftvårdsförbund 2010). Contact persons have been Ann Häger and Lotten Jönsson at Malmö's municipality (Jönsson 2010). The spatial information and some of the attributes originate from The National Road Database (NVDB). The NVDB is maintained by the Swedish TA and has been developed in collaboration between them, the Swedish mapping, cadastral and land registration authority, the County Councils, the Municipalities and the Swedish forest industries. The database contains information about governmental, municipality and private roads (Mattsson 2008a).

The attributes of the roads originate from different sources depending on road size and type. Information about speed limits comes from SAPU, while the traffic flow data are of different origins. Measurements have been made for larger roads, which means governmental roads maintained by the National Road Administration, but also for some of the roads maintained by the municipalities. For roads where measured data is missing, different methods have been used to estimate traffic densities. Some estimates were made using the model Emme (2010), which is a well-accepted software for modelling traffic flows. Other values have been estimated with gap filling, which means that missing values have been filled based on values on both sides of the road segment. Traffic values of smaller and private roads were estimated. The modelling and estimations of traffic flows have been made by SAPU (Jönsson 2010). The uncertainty in traffic intensity is estimated to be $\pm 20\%$, but it varies between different road segments (Gustafsson 2007). The error is smaller for highly trafficked roads and larger for smaller roads. The spatial distribution, information about the length of roads and information about estimations of traffic flow types are given in Appendix B.

Building data

Polygons over the buildings used in the study come from a database called Skånekartan (Appendix C). The database Skånekartan has been developed in collaboration between the Swedish mapping, cadastral and land registration authority and Geodatacenter Skåne AB, a company owned by the county of Scania and its 33 municipalities. The data contains information about buildings in Scania. Each building is represented with one polygon, and the database is updated 2 times per year. The municipalities record buildings that lie within population centers while the Swedish mapping, cadastral and land registration authority (Lantmäteriet) records buildings that lie outside of population centers.

Laser elevation data

Elevation data in the study comes from a laser scanning of Burlöv's and Malmö's municipalities in the spring of 2008. Malmö's and Burlöv's municipalities ordered the laser scanning and elevation model from a Danish company that no longer exists. Information about the measurements was therefore obtained orally from Malmö municipality (Iric 2010). The laser scanning measurements were made with a green laser at a height of 1000 m. One elevation point was recorded for each m^2 (Iric 2010). The uncertainty in the measurements was estimated to be 3-7 cm vertically and 1 m horizontally. After scanning the ground surface, buildings and vegetation were identified in the DSM and subtracted. This was done to create a DTM, where the height of vegetation and buildings was excluded and new elevation interpolated. From the DTM contour lines over the elevation were created.

Information about elevation was given in three layers, two point layers and one layer containing lines. The two point layers were one Digital Surface Model (DSM) and one Digital Terrain Model (DTM). A DSM contains information about height in the landscape with buildings and vegetation included while a DTM contains information about elevation without buildings and vegetation included. The line layer contained elevation information in form of contour lines with an equidistance of 0.25 m.

Elevation data are missing for two small pieces of the study area: in the northeast and the southwest corners (Figure 10). Most of the missing elevation data is in the 300 m buffer zone created around Burlöv's municipality and the area is sparsely populated (there are only seven buildings). Therefore, it is believed that the possible average error in the noise simulation because of this effect has a low impact on the final results.

Satellite elevation data

Elevation data was downloaded from the National Aeronautics and Space Administration's (NASA) homepage (Appendix A). An Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) instrument using an along-track scanner produced the Digital Elevation Model (DEM). The DEM covers earth's land surfaces between 83 N and 83 S and each of the satellite scenes images corresponds to about 60x60 km of ground area. The resolution of the DEM is 30x30 m.

Land cover data

Land cover data refers to the data used for ground correction in the Road Traffic Noise – Nordic prediction method. The land cover data was developed by the European Environment Agency (EEA) and was downloaded from the Internet (Appendix A). Spatial distribution regarding the softness of the ground is given in Appendix D.

Noise wall data

The noise wall data come from Burlöv's municipality and represent spatial information about noise walls and noise barriers within the municipality (Appendix A). The data were collected in the spring of 2010 (Svensson 2010) (Appendix E).

Population data

The population data represents individuals living in one real estate with one point per person in the centroid of the real estate. Data used in this study are from September 31st 2009 and originates from Scania regional council (Appendix A).

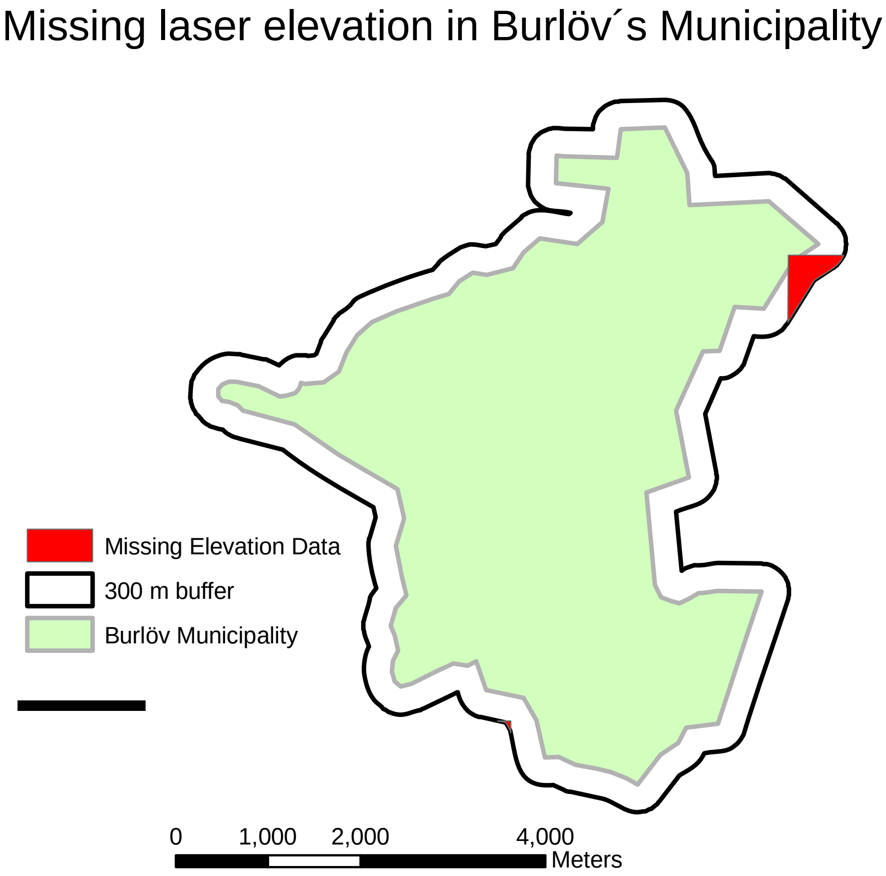

Figure 10: In small areas in the north east and the south west parts of the study area information about laser elevation is missing.

3.3 Software

The analyses were made in the software SoundPLAN 7.0, which is a software specialized in noise and air pollution modelling. Experts within the subjects have developed the program and it is possible to calculate noise with more than 50 different calculation standards, such as the RTN (Jonasson *et al.* 1996). SoundPLAN is the noise simulation software with most users across the world and it has also been the market leader for the last 20 years (SoundPLAN 2010).

4. Method

All calculations of noise exposure are based on the RTN (Jonasson *et al.* 1996) that is explained in more detail in chapter 2. A flow chart showing general steps of the method is attached in Appendix F.

4.1 Preparation of data

The first step was to collect all needed data. Data originated from different sources, which meant that it needed to be prepared before it could be used to model noise exposures. Most of the preparations where made in ArcMap (ESRI 2010).

All data used was either delivered in, or re-projected to, the reference system SWEREF 99. It is possible to adjust the central meridian when projecting in SWEREF 99, in order to make the projection over a specific area more accurate. The coordinate system SWEREF 99 13 30 was therefore used, since it gives the best representation of Scania (The Swedish mapping, cadastral and land registration authority 2010).

4.1.1 Roads

There are five attributes connected to the data on spatial distribution of roads:

- Average Daily Traffic (ADT)
- Heavy/light vehicles
- Diurnal distribution of vehicles
- Speed limits
- Road width

A unique ID-number was given to each road segment, to enable identification of road segments when importing and exporting information between different software.

Average Daily Traffic
Information about this attribute was available in the road data (see chapter 3).

Heavy/light vehicles
The percentage distribution of light and heavy vehicles was provided in the road data (see chapter 3).

Diurnal distribution of traffic
Diurnal distribution of traffic intensity varies (Bendtsen 1999). This is important to take into consideration when modelling noise levels from roads, since sound exposure levels should be reported as L_{den} according to the EU (2002/49/EG 2002). Noise recorded during evening-time gets a 5 dB(A) penalty while noise recorded during night-time gets a 10 dB(A) penalty (2002/49/EG).

In a best case scenario the diurnal distribution (24 h) of traffic is known and in other cases estimations need to be done. Burlöv's municipality was asked about the traffic distribution in the municipality, but they had no figures and directed to NVDB. No figures about the diurnal distribution of traffic were found in NVDB so estimations were made based on former studies (Bendtsen 1999, Kujala 2002, Appelberg 2007, Jonasson 2009). The distribution of traffic varies depending on which type of road and amount of traffic. Based on the studies above three types of distributions were used: urban, rural and highly trafficked roads.

For urban roads (Figure 11) the diurnal distribution of traffic was set to 80% day, 15% evening and 5% night. This was based on the distribution 80% day, 16% evening and 4% night describing a general diurnal distribution of vehicles in cities (Bendtsen 1999) and the distribution 80% day, 15% evening and 5% night specifically describing the diurnal distribution in Malmö's municipality (Appelberg 2007).

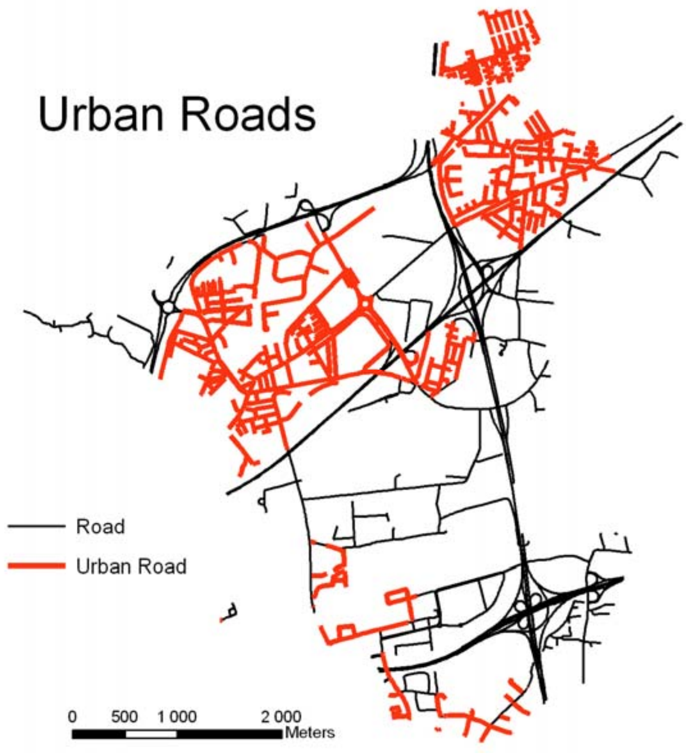

Figure 11: Distribution of urban roads in Burlöv´s municipality.

For highly trafficked roads (Figure 12) the diurnal distribution from the Swedish TA was used. This diurnal distribution was set to 75% day, 10% evening and 15% night (Jonasson 2009). In this study, roads with speed limits of 90 km/h and 110 km/h were classified as highly trafficked roads.

The diurnal distribution of rural roads (Figure 13) was set to 70% day, 20% evening and 10% night. These figures were based on a noise mapping performed in Gothenburg (Hammarlund 2007) where unknown diurnal distributions of roads were set to these values. This was strengthen with values from a noise investigation made of Stockholm (Kujala 2002) where a general distribution of roads was set to 72% day, 20% evening and 8% night.

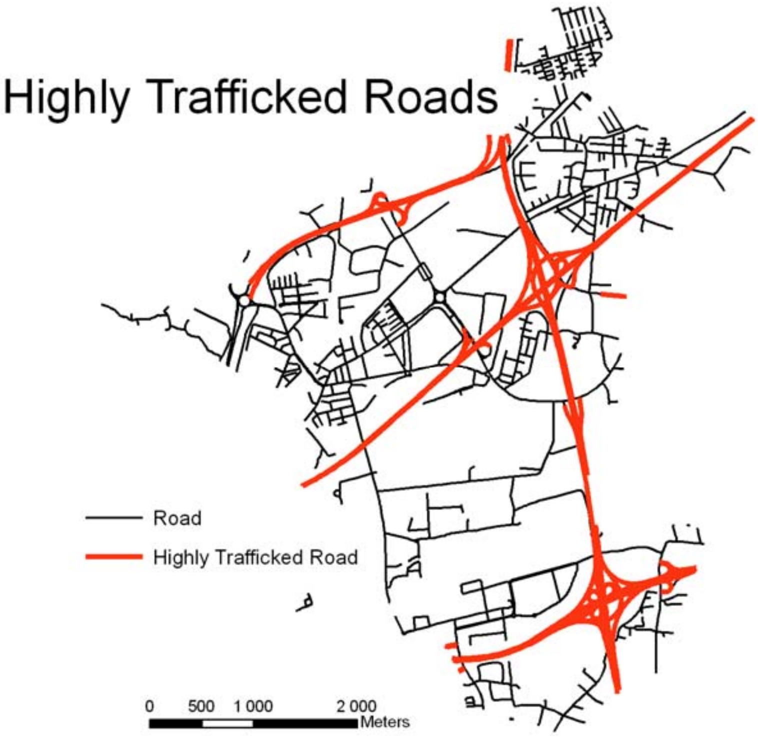

Figure 12: Distribution of highly trafficked roads in Burlöv´s municipality.

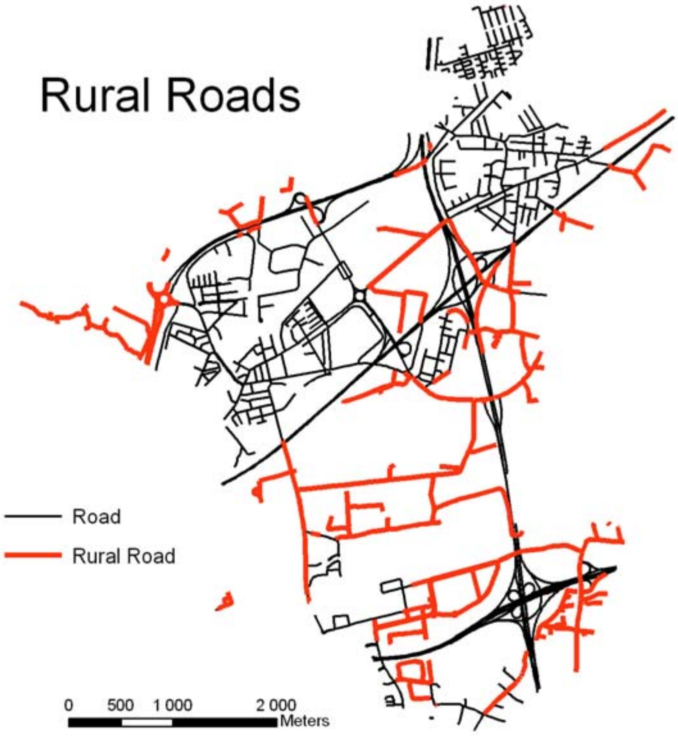

Figure 13: Distribution of rural roads in Burlöv´s municipality.

Speed limits
Information about the speed limits on the roads was based on information from SAPU (Jönsson 2010; Appendix A). The speed limit information was based on the speed limit set for light vehicles. Light vehicles include private cars, light trucks and vehicles on two wheels.

Heavy vehicles such as buses and trucks have different speed limits. Buses are allowed to drive at a maximum speed of 90 km/h and the same rules apply for trucks driving at motorways. Trucks not driving at motorways are allowed to drive at a maximum speed of 80 km/h (The Swedish Transport Administration 2008). A simplification of the above described speed limits was made and the maximum speed limit for heavy vehicles (including buses and trucks) was set to 90 km/h.

Road width
Information about road width was given from NVDB. In five out of 1760 road segments information about the width was missing and they were given the width 4 m.

4.1.2 Buildings

Two attributes were connected to the polygon layer containing buildings:

- Residential building or not
- Height of the building

As for the roads data, the preparation of the buildings data started with assigning an attribute with an ID number for each building. This ID made it possible to identify specific buildings when working between different software.

Residential buildings
All buildings act as screens but noise exposure was only calculated for residential buildings. Residential buildings were selected based on some criteria. Available building polygons were divided into four different building types. Two of these building types were classified as residential. Out of these noises were not calculated for residential buildings with an area smaller than 15 m^2 and a height lower than 3 m. All buildings lower than 2.5 m (independent of area) were also classified as non-residential buildings. The distribution of all buildings within the study area as well as the distribution of residential buildings within Burlöv's municipality is illustrated in Appendix C.

Building Height
The height of the buildings was not known. Information about elevation in Burlöv's municipality, accounting and not accounting for buildings, was available in the form of a laser-scanned DTM and a laser-scanned DSM. The spatial distribution of the buildings was also known as a polygon layer. This combined information was used to extract the height of the buildings.

Information about the elevation in the study area had been collected with one point per square meter (Iric 2010). All points within the building polygons were extracted from both the DTM and DSM. For both the DTM and the DSM the point with the highest value was set to represent the height of the whole building polygon. The point value from the DSM was then subtracted from the DTM value to get the height of the building.

The noise calculation points, called receivers, were placed on the façades of buildings at a height of 4 m according to the END-directive (2002/49/EG 2002). All residential buildings were therefore given a minimum height of 4.5 m in order to be able to place a receiver at all façades. 2515 of 6483 residential buildings in the study area had a height lower than 4.5 m and were therefore assigned this height. All buildings acted as screens.

4.1.3 Ground correction

According to the RTN (Jonasson *et al.* 1996) the correction for reflection against a hard or a soft surface differs (see chapter 2). Land cover data used in this study are the European land use dataset Corine. The geometric resolution of the dataset is 100*100 m (Nunes de Lima 2005). In the study area 9 of 48 land cover classes available in Corine were represented and all of these 9 classes belong to either of the two main classes agricultural land or artificial surface. In order to decide whether a surface was hard or soft impedance measures were used. Impedance gives a measure of how much of a sound that is reflected from a surface. The higher the impedance, the more sound is reflected. The impedance of each land cover class was assigned based on a report from the Swedish National Testing and Research Institute (Sohlman 2004). The definition of hard ground according to Jonasson *et al.* (1996) is ground covered by concrete, asphalt, water or other sound reflecting materials. Bendtsen (1999) interprets soil without vegetation to be such an ”other sound reflecting material”. Based on this and on impedance classes from Nord 2000 (Jonasson & Storeheier 2001), ranging from 12.5 to 10000, the limit for hard ground was set to an impedance of 2000 or more An impedance of 2000 or more corresponds to compact dense ground (gravel road, parking lot) and hard surface (dense asphalt, concrete, water) (Sohlman 2004).

Distribution of both impedance classes and hard and soft ground is illustrated in Appendix D.

4.1.4 Topography

The elevation data used to map the noise levels in all of Burlöv was the laser data. These data were available in the form of contour lines. To make calculations faster a geometry filter (filter to simplify lines) of 0.2 m were used when data were imported into SoundPLAN. This meant that the contour line at the most could be moved with 0.2 m from its original position. These contour lines were recalculated to a Digital Ground Model (DGM) to enable SoundPLAN to use the elevation data. A DGM contains elevation of the surface of the ground.

4.1.5 Noise walls

The correction for noise walls was based on the height of the wall. Spatial information about noise walls were available for Burlöv’s municipality (Svensson 2010), and to many of these wall segments, information about height and a short description was attached. Information about all larger noise walls in Burlöv’s municipality was available (Appendix A) and all these wall segments with information about wall height were included in the noise mapping.

4.1.6 Common work up of the data in SoundPLAN

After the data had been prepared it was imported into SoundPLAN. The analysis of noise exposure was made in 3D and elevation values were therefore assigned to roads, buildings and noise walls. Elevation was assigned based on the DGM that was calculated from the contour lines. This created a 3D model of Burlöv's municipality in SoundPLAN (Figure 14).

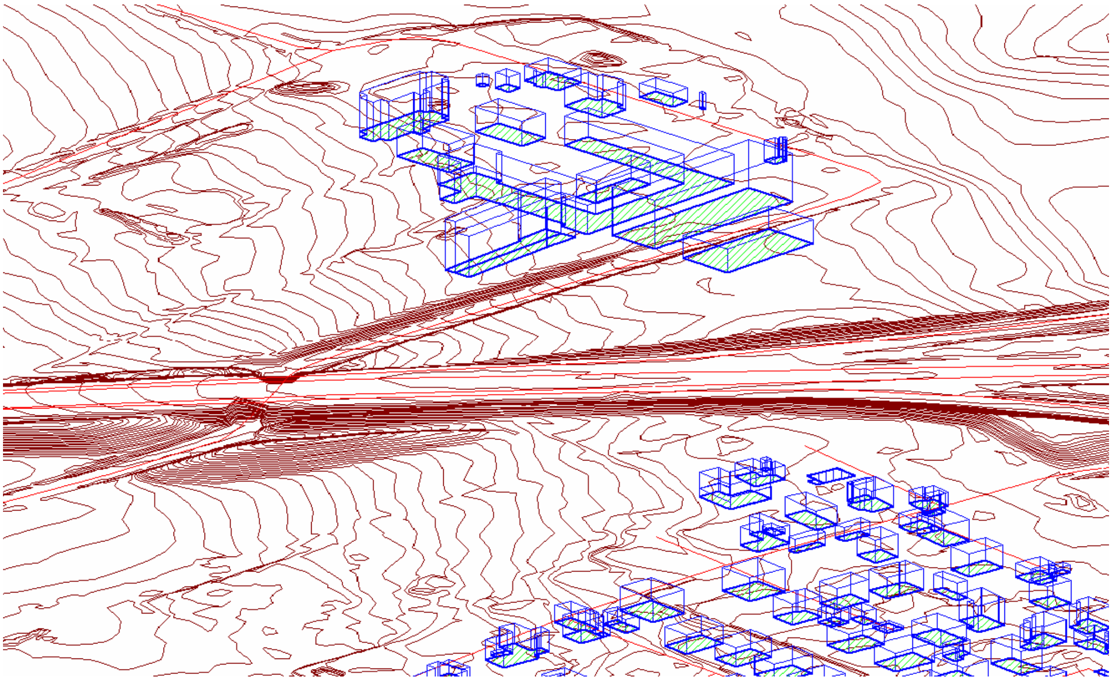

Figure 14: Screen shot from a part of the study area. Blue cubes are buildings, dark red lines are elevation lines and bright red lines are roads.

When assigning height to roads they were draped over the DGM, information about for example bridges was therefore missed. This was corrected for through visual identification of bridges and through indications from SoundPLAN – where a road segment had more than a 30 degree slope were identified as a bridge (Figure 15).

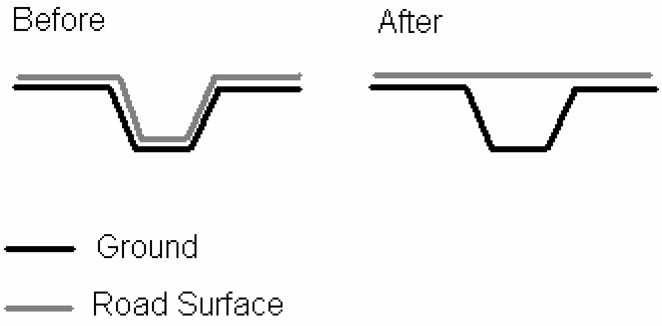

Figure 15: When roads were given elevation information they were draped over a digital ground model (before). This resulted in height differences between the model and reality. Corrections of the height were made where bridges were digitized (after).

Elevation was assigned to buildings based on the average elevation above sea level for all coordinates in the building polygon.

SoundPLAN is specialized software and therefore needs to have the data in a certain format. There are different problems that can occur and they are mostly related to the geometry of the data. Some smaller corrections were made based on this depending on error messages when calculating. A couple of road segments were manually moved about a meter sideways and three very small road segments (shorter than 1 m) were deleted. Coordinates close to each other result in errors, when calculating sound levels in SoundPLAN. The program therefore has a function that filters points that are closer than 1 cm apart. This function was used only on the road layer.

4.2 Modelling noise exposure

All calculations of noise exposure were made based on RTN (Jonasson *et al.* 1996) within the software SoundPLAN. Corrections were made in steps 1-3 (basic noise level, distance correction and ground and screen correction) in the RTN. Also a number of the corrections under step 4, including angle of view, road gradient, short distance to road and single reflection from a vertical surface, were made. No corrections were made for façade corrections according to step 5, since outdoor noise levels were calculated.

Two different calculation types were used to map the noise exposure in the study area: one method that mapped the number of persons exposed to different noise levels, and one that mapped the spatial distribution of noise exposure over the study area. Both calculation types had the same input data and the same considerations to different factors. The main difference between them was the placement of receivers. Reflections from buildings own façades were suppressed according to the END-directive (2002/49/EG 2002) when mapping the number of exposed persons but not when mapping the area exposed. For both methods sources were searched for 360 degrees around the receiver.

4.2.1 Estimating the number of persons exposed

To quantify the number of persons exposed to different noise levels (L_{den}, L_{night}, L_{Aeq24} and $L_{AF\max}$), noise exposure was calculated for each façade of all residential buildings. The total number of persons included in the study was 16166.

Population data of persons living in Burlöv's municipality was connected to the closest residential building and assumed to be exposed to the highest recorded noise level of the façade of each building. This type of calculation is called façade noise mapping. The façade noise was calculated for all façades of all residential buildings. However, according to the EU (2002/49/EG 2002) only the most exposed façade should represent the noise exposure for a whole building.

Façade noise mapping is a calculation method that is well suited for calculation of sound levels over large areas where detailed information is required. Receivers were distributed at a height of 4 m along façades of residential buildings, one per façade, in the calculation area according to the END-directive (2002/49/EG 2002).

Search Area

Noise exposure modelling can be very computation demanding, especially when calculated over a larger area. The sound pressure level from a source will decrease with the distance to the source as described above (section 2.4.1). Two sources contributing with equally large sound exposure levels, but from different distances, will contribute with different sound pressure levels at the receiver. The source closest to the receiver will have the greatest influence (Jonasson *et al.* 1996). If all sources would be included when calculating over large areas, the calculation time would be very long. There is therefore a need to limit the spatial extent of the calculation for each of the calculation points.

In the implementation of the RTN in SoundPLAN, a search area sets this limitation. This search area refers to the distance between the receiver and the source. If the search area is set to for example 100 m, all sources within a radius of 100 m from the receiver will be included in the calculations (Figure 16). According to the RTN the calculation method has been validated up to 300 m from the calculation point (Jonasson *et al.* 1996). This might be a problem because if the search area is set to 300 m no concern at all will be paid to sources outside of this range. According to former studies search areas longer than 300 m have been used (Appelberg 2007; Hammarlund 2007; Kujala 2002). But there have also been studies made with 300 m search radius (Persson *et al.* 2007).

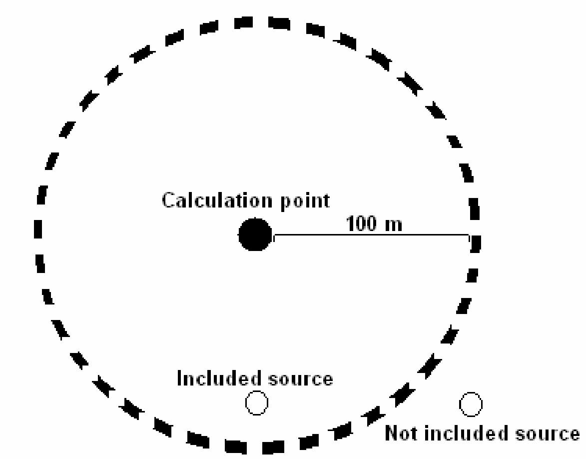

Figure 16: Sources within a search area with a radius of 100m are included when calculating noise exposure levels at the calculation point (the receiver).

It is more important to have a large search area if there are strong sources such as motorways, because these will influence larger areas. Based on this, mapping of noise in Burlöv's municipality was made both with a 300 m and a 1000 m search radius. Burlöv's municipality have an area of about 19 km^2, which means that neither of the mappings will include all sources in the municipality, but when using a 1000 m search area all buildings in the municipality will be affected of at least one road with a speed limit of 90 km/h or higher. Using a larger search radius than 300 m will increase the uncertainty in the model (Jonasson *et al.* 1996) and these calculations therefore acted as reference calculations.

Reflections

In SoundPLAN it is possible to govern the number of reflections. According to the RTN (Jonasson *et al.* 1996) the number of needed reflections varies depending on the surface.

When dealing with vertical surfaces the number of needed reflections is considered to be one. In a more complicated landscape, like in a city, it is better to use two or three reflections, since the sound bounces between buildings. In this study one reflection was included because of the much longer calculation time in SoundPLAN when using three reflections and small differences in results between one and two reflections in the sensitivity analysis (see 5.3).

Time period

When calculating L_{den} the diurnal distribution of traffic needed to be divided into three parts in order to distribute the penalties, 5 dB(A) to evening hours and 10 dB(A) to night hours. The day was defined from 06.00-18.00, the evening between 18.00-22.00 and the night between 22.00-06.00 (Kujala 2002).

Connecting the result from the façade noise exposure to the façades spatially

The result from the façade noise mapping was given in the form of a table with the noise exposure of all the receivers. There was no spatial information connected to the table, but each receiver had a building id. This id number was used to connect the result from the noise modelling to the polygon layer containing buildings in Burlöv. The highest façade value for each building was selected to represent the noise exposure of the whole building.

Population exposure

Population points where linked to the building polygons based on the Euclidean distance between the point and the nearest building (Figure 17). Population points were only connected to buildings classified as residential. All persons living on a real estate was represented in one population point in the centroid of the real estate. Population data were protected by secrecy and therefore Emilie Stroh (2010) the Department of Medicine at Lund University, did the linking of the noise exposure to persons exposed.

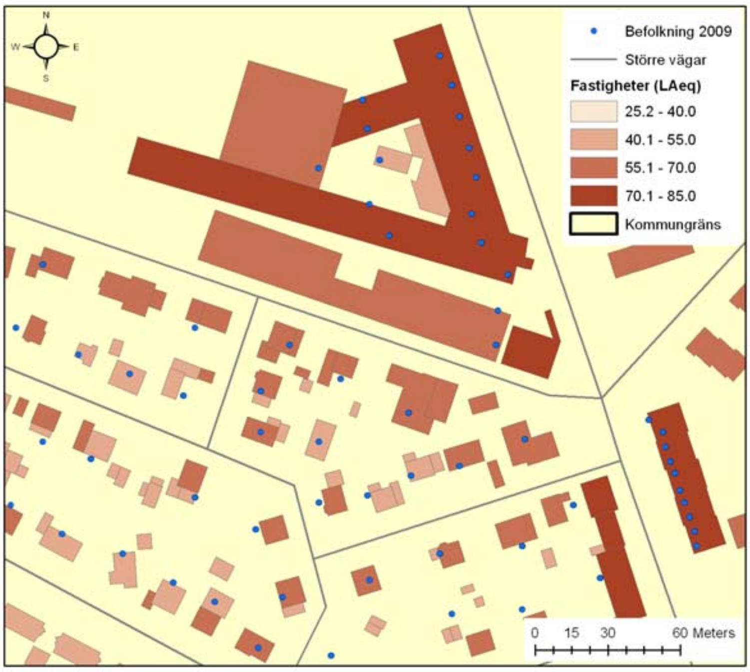

Figure 17: Points in the population data were connected to the closest buildings using Euclidean distance.

4.2.2 Area distribution of noise exposure

According to the EU (2002/49/EG 2002) not only the façade levels of noise should be calculated, but also the area exposed to different noise levels. This can be calculated with so-called grid noise mapping. Grid noise maps are used to describe the sound levels outside buildings, for example on the streets and in nature. The receivers were placed in a grid over Burlöv´s municipality. The noise level was calculated for each cell in the grid. The size of the cells in the grid can be decided by the user, a smaller cell means higher accuracy and longer calculation time and a larger cell means lower accuracy but faster calculation time. In this study a grid size of 10 m was used. The height of the receivers was set to 4 m to correspond to the façade noise levels. Area calculations are very heavy and the computer capacity was limited, a tolerance level of 0.5 dB(A) was therefore selected. This means that the uncertainty in each calculation point increases with 0.5 dB(A). This is a built in function in the software SoundPLAN to simplify the calculations. The same data and method as in the façade noise calculation were used.

Maps over the area distribution were exported from SoundPLAN as contour lines and visualized in ArcMap. When calculating the area of different noise level exposure the ground covered by buildings was not included (outdoor levels were calculated). Distribution between different noise levels was summarized in table format.

4.3 Sensitivity analysis

To compare different input data and different factors influence on noise mapping, several façade noise maps were calculated for a small test area. The small test area was situated in the north of Burlöv’s municipality and contained 126 residential buildings (Appendix G). The number of façades that noise levels were calculated for was 663. The topography in the area was flat and the area represented average conditions in Burlöv’s municipality.

The small study area only limited which residential buildings to include in the noise mapping and noise sources from within the search area for the whole of Burlöv’s municipality were included when calculating noise levels. A reference calculation was made with the same factors as described in the façade noise mapping over all of Burlöv’s municipality. The search radius was set to 300 m and all ground within the 300 m buffer zone around the area was soft. This means hard ground was only affecting when using a search radius longer than 1000 m and including hard ground.

One parameter or one type of data was changed at a time and compared to the reference calculation. The factors and data influence that were tested were :

- Zero and three reflections
- Using ASTER elevation data instead of elevation from laser data
- Different search radius: 500 m, 1000 m and 2000 m
- Increased traffic: 10%, 20% and 50%
- All buildings had a height of 8 m
- Searching for sources in 180 degree (only in front of the façade)
- 2 m high protection wall along the large roads west of the search area

All façades were included in the results, not only the highest façades for each building. Mean values for all façades for each calculation was calculated and graphs were made showing the façade noise levels for each calculation plotted against the percentage of façades exposure.

5. Results

5.1 Number of persons exposed to different noise levels

Persons exposed to L_{Aeq24}

About one third of the population in Burlöv's municipality is exposed to noise levels >55 dB(A) L_{LAeq24} using a 1000 m search radius (Table 1). With a 300 m search radius about one fourth of the population is exposed to levels over the 55 dB(A). The distribution of percentage of population plotted against noise level for L_{LAeq24} is shown in Figure 18. Differences in percentage of population exposed decrease with increased noise level. The difference in maximum and minimum exposure for one receiver for both a 300 m and a 1000 m search radius is presented in Table 2.

Table 1: Number of persons exposed to L_{Aeq24} >50 dB(A) and corresponding percentage of total population in Burlöv (16166) for both a 300 m and a 1000 m search radius.

	Number of persons exposed	
LAeq24 dB(A)	**using 300 m search radius (%)**	**using 1000 m search radius (%)**
>50 -55	3069 (19.0)	4999 (30.9)
>55 - 60	2642 (16.3)	3773 (23.3)
>60 - 65	1172 (7.2)	1208 (7.5)
>65 - 70	163 (1.0)	167 (1.0)
>70	2 (0.0)	2 (0.0)
Total > 55	**3979 (24.5)**	**5150 (31.8)**

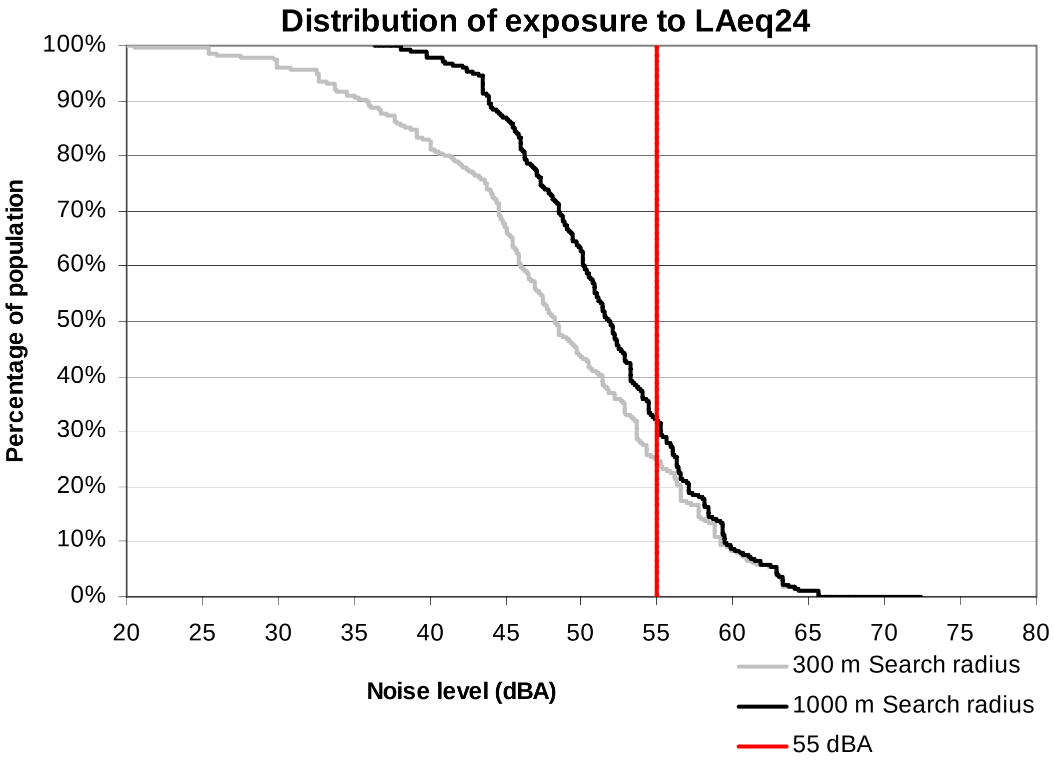

Figure 18: Percentage of exposed population plotted against exposure of L_{LAeq24} for a 300 m and a 1000 m search radius.

Table 2: Maximum and minimum L_{Aeq24} when using a 300 m and a 1000 m search radius.

Laeq24 dB(A)	300 m search radius	1000 m search radius
Min	14.99	36.39
Max	72.33	72.35

Persons exposed to L_{den}

Results for the number of persons exposed to the EU measure L_{den} are shown in Table 3 below. When using a 1000 m search radius the number of exposed persons to the limit of 55 dB(A) is over 50% in Burlöv's municipality. About 38% is exposed to levels >55 dB(A) when using a 300 m search radius. The distribution of percentage of population plotted against noise level for L_{den} is shown in Figure 19. The differences in exposure between the 300 m and the 1000 m search radii are higher for lower noise levels and decrease with increasing noise exposure (Figure 19). This difference is also shown in Table 4, which shows the maximum and minimum noise levels based on the 300 m and the 1000 m search radii. There is no difference in maximum exposure between the two search radii.

Table 3: Number of persons exposed to L_{den}>50 dB(A) and corresponding percentages of total population in Burlöv (16166) for both a 300 m and a 1000 m search radius.

	Number of persons exposed	
Lden dB(A)	**using 300 m search radius (%)**	**using 1000 m search radius (%)**
>50 -55	2709 (16.8)	4480 (27.7)
>55 - 60	2888 (17.9)	4219 (26.1)
>60 - 65	2317 (14.3)	2994 (18.5)
>65 - 70	893 (5.5)	956 (5.9)
>70 - 75	17 (0.1)	17 (0.1)
>75	2 (0.0)	2 (0.0)
Total > 55	**6117 (37.8)**	**8188 (50.6 %)**

Table 4: Maximum and minimum L_{den} when using a 300 m and a 1000 m search radius.

Lden dB(A)	300 m search radius	1000 m search radius
Min	17.5	40.4
Max	76.4	76.4

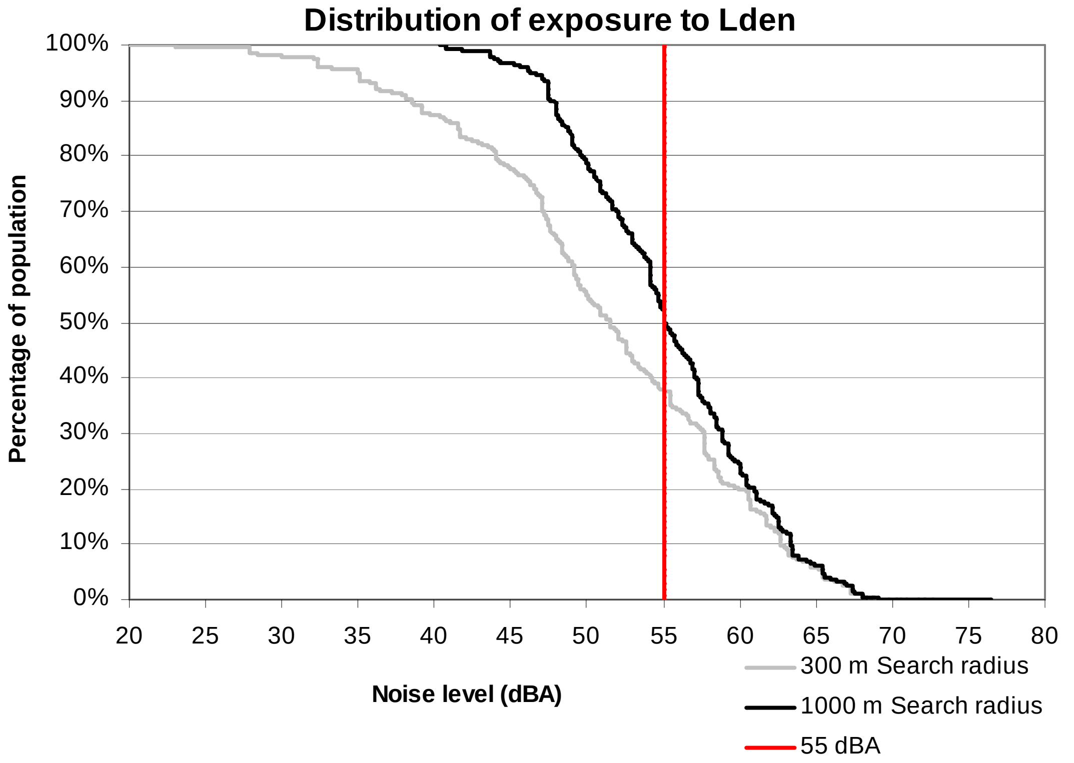

Figure 19: Percentage of exposed population plotted against exposure of L_{den} for a 300 m and a 1000 m search radius.

Persons exposed to L_{night}

The number of persons exposed to noise when using the second EU measure L_{night} is lower than when calculating L_{LAeq24} and L_{den} (Table 5). The guidelines is on the other hand stricter, this results in more persons exposed to L_{night} higher than the threshold of 45 dB(A) (Berglund, Lindvall & Schwela 1999). The distribution of percentage of persons exposed plotted against exposure level follows the same pattern as for L_{Aeq24} and L_{den} (Figure 20). There is a large difference between the minimum exposures when using a 300 m radius and a 1000 m search radius (Table 6). The maximum exposure is almost the same for the two different search radii.

Table 5: Number of persons exposed to L_{night} >40 dB(A) and corresponding percentages of total population in Burlöv (16166) for both a 300 m and a 1000 m search radius.

Lnight dB(A)	Number of persons exposed using 300 m search radius (%)	using 1000 m search radius (%)
>40 - 45	2731 (16.9)	3530 (21.8)
>45 - 50	2191 (13.6)	4929 (30.5)
>50 - 55	2839 (17.6)	3536 (21.9)
>55 - 60	1315 (8.1)	1441 (8.9)
>60 - 65	40 (0.2)	47 (0.3)
>65	2 (0.0)	4 (0.0)
Total > 45	**6387 (39.5)**	**9957 (61.6)**

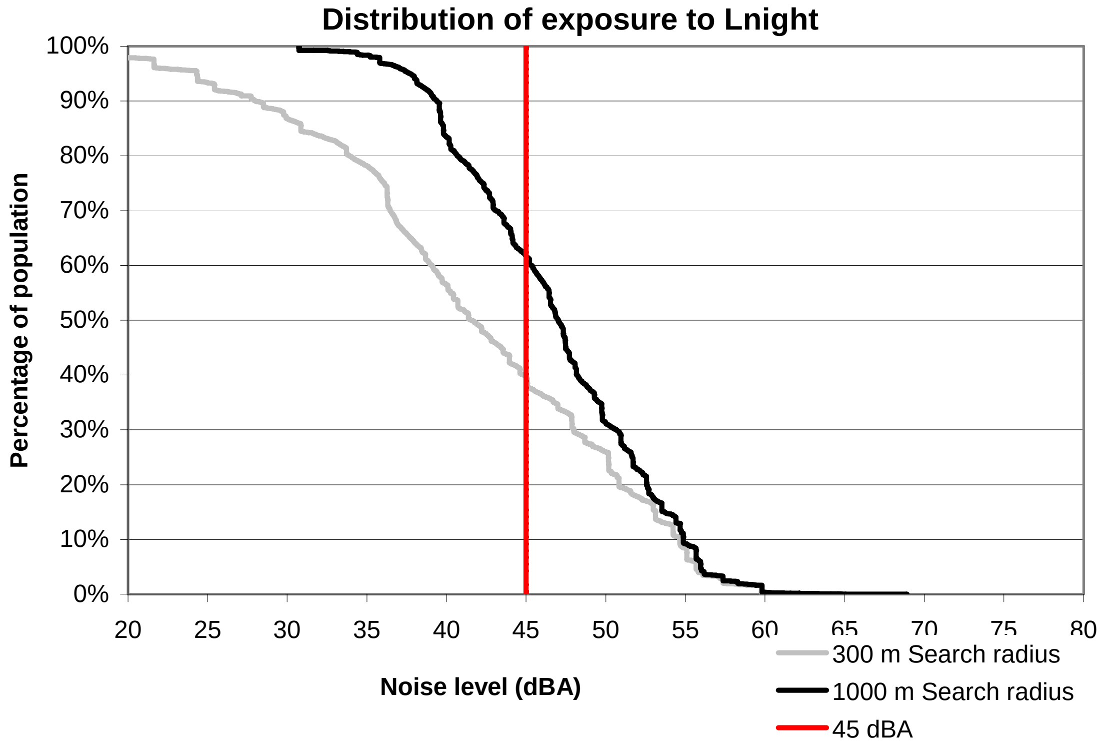

Figure 20: Percentage of exposed population plotted against exposure of L_{night} for a 300 m and a 1000 m search radius.

Table 6: Maximum and minimum L_{night} when using a 300 m and a 1000 m search radius.

Lnight dB(A)	300 m search radius	1000 m search radius
Min	6.75	30.73
Max	68.86	68.88

Persons exposed to $L_{AF\max}$

The number of persons exposed to maximum levels are the same for > 70 dB(A) for the 300 m and the 1000 m search radii (Table 7). There are very small differences between the radii of 300 m and 1000 m, which can be seen for lower exposure levels. Since differences are very small they are not presented in this study. The distribution when plotting the percentage of persons exposed against the maximum level are almost identically for both the 300 m search radius and the 1000 m search radius (Figure 21). Maximum and minimum exposure levels, are identical for both the 300 m and the 1000 m search radii (Table 8).

Table 7: Number of persons exposed to $L_{AF\max}$>60 dB(A) and corresponding percentages of total population in Burlöv (16166) for both a 300 m and a 1000 m search radius.

	Number of persons exposed	
Lmax dB(A)	using 300 m search radius (%)	using 1000 m search radius (%)
>60-65	1663 (10.3)	1669 (10.3)
>65-70	3749 (23.2)	3743 (23.2)
>70-75	4711 (29.1)	4711 (29.1)
>75-80	2269 (14.0)	2269 (14.0)
>80-85	1071 (6.6)	1071 (6.6)
>85	338 (2.1)	338 (2.1)
Total > 70	**8389 (51.9)**	**8389 (51.9)**

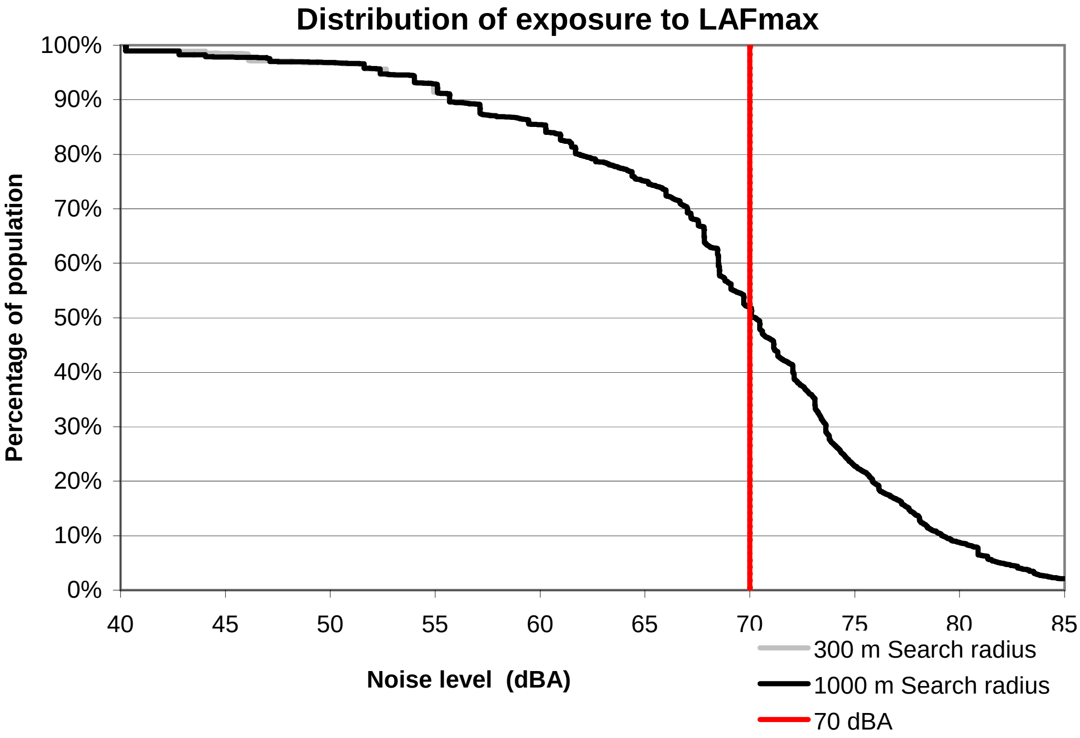

Figure 21: Percentage of exposed population plotted against exposure of $L_{AF\max}$ for a 300 m and a 1000 m search radius.

Table 8: Maximum and minimum $L_{AF\max}$ when using a 300 m and a 1000 m search radius.

LAFmax dB(A)	300 m search radius	1000 m search radius
Min	40.24	40.24
Max	90.35	90.35

5.2 Area exposed to different noise levels

The area distribution of different noise levels was calculated for the four measures L_{den}, L_{night}, L_{Aeq24} and $L_{AF\max}$. The total area of Burlöv's municipality without buildings is 18.75 km^2. The spatial distribution of noise exposure is presented in Appendix H for all four measures and for both search radii 300 m and 1000 m. Appendix H also includes tables showing exposed area and percentage of persons exposed for 5 dB(A) intervals between 35 dB(A) and 85 dB(A). The area exposed of the different measures when using a 1000 m search radius is presented in Table 9. $L_{AF\max}$ is the measure that has the biggest spatial distribution of noise levels over 55 dB(A) followed by L_{den}. Percentages of area distributed between different noise levels are shown in Table 10. Over 50 % of the area in Burlöv is exposed to noise levels over 55 dB(A) when calculating L_{Aeq24} and over 68 % when calculating L_{den}.

Table 9: Areas exposed to noise levels of >55, >65 and >75 dB(A) respectively when using different noise measures and a 1000 m search radius.

1000 m Noise level dB(A)	LAeq24 (km2)	Lden (km2)	Lnight (km2)	LAFmax (km2)
>55 dB(A)	9.55	12.83	6.17	14.8
>65 dB(A)	3.18	4.91	1.98	10.04
>75 dB(A)	0.81	1.54	0.36	5.36

Table 10: Percentage of area exposed to noise levels of >55, >65 and >75 dB(A) respectively when using different noise measures and a 1000 m search radius.

1000 m Noise level dB(A)	LAeq24 (%)	Lden (%)	Lnight (%)	LAFmax (%)
>55 dB(A)	50.9	68.4	32.9	78.9
>65 dB(A)	17	26.2	10.6	53.5
>75 dB(A)	4.3	8.2	1.9	28.6

The area exposed to levels 55 dB(A) is smaller when using the 300 m search radius than when using the 1000 m search radius (Table 11 and 12). The difference in using a 300 m search radius instead of 1000 m is largest for L_{den} and smallest for L_{night}. Differences between 300 m and 1000 m search radii are smaller for higher noise exposures for all measures.

Table 11: Areas exposed to noise levels of >55, >65 and >75 dB(A) respectively when using different noise measures and a 300 m search radius.

300 m Noise level dB(A)	LAeq24 (km2)	Lden (km2)	Lnight (km2)	LAFmax (km2)
>55 dB(A)	7.72	9.32	5.26	15.23
>65 dB(A)	3.05	4.49	1.94	10.08
>75 dB(A)	0.8	1.51	0.35	5.32

Table 12: Percentage of area exposed to noise levels of >55, >65 and >75 dB(A) respectively when using different noise measures and a 300 m search radius.

300 m Noise level dB(A)	LAeq24 (%)	Lden (%)	Lnight (%)	LAFmax (%)
>55 dB(A)	41.2	49.7	28.1	81.2
>65 dB(A)	16.2	23.9	10.3	53.8
>75 dB(A)	4.2	8.0	1.9	28.4

5.3 Sensitivity analysis

Under this section the result of the study of how different factors affect the noise level over a small study area is presented. Differences in all factors are compared to a reference model. The reference model had the same settings and data as the main study and a 300 m search radius. In the table below the reference model is presented in italic style.

Search radius

Increasing the search area gives an increase in the mean exposure of the façades (Table 13). Calculation time also increases strongly with increased search radius. The difference in exposure is larger when the search radius is increased from 300 m to 500 m than it is when increased from 500 m to 1000 m. Figure 22 shows percentage of façades exposed plotted against noise exposure level. The difference in exposed façades is larger for lower exposure levels than for higher.

Table 13: Mean noise exposures for all façades inside the small study area, for different noise measures and search radii. Italic text marks the reference model with same factors as the main study.

Search radius	Lden dB(A)	Lnight dB(A)	Laeq24 dB(A)	Lmax dB(A)	Run time
300 m	*43.6*	*34.9*	*40.2*	*52.3*	*7 min 30 sec*
500 m	53.2	45.4	49.2	53.0	20 min 23 sec
1000 m	55.8	48.2	51.8	52.9	47 min 24 sec
2000 m	56.7	49.1	52.7	52.8	1 h 56 min 34 sec

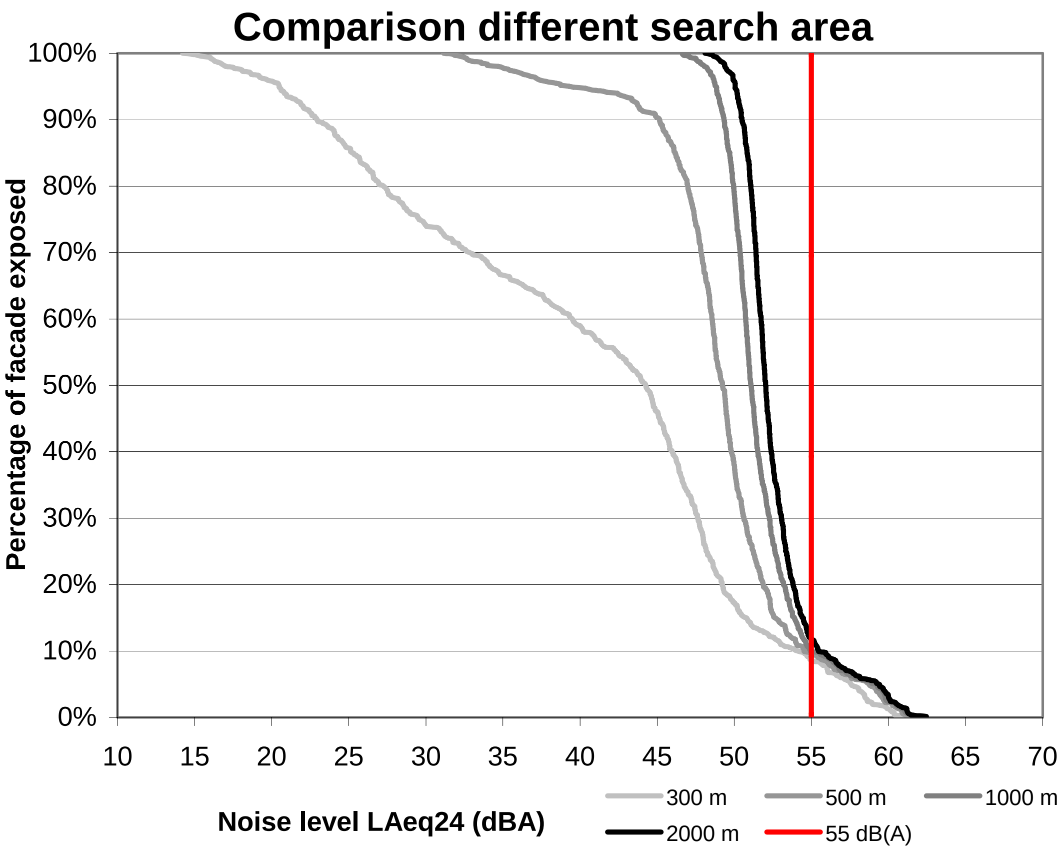

Figure 22: Percentages of exposed façades plotted against different noise levels. The number of façades exposed to higher levels of noise increases with increased search radius. 55 dB(A) states the Swedish threshold value. The difference is largest for low exposure levels.

Traffic increase

A traffic increase with 10% correspond to an increase of 0.4 dB(A) in mean exposure in the area (Table 14). The time to run the calculations is not affected by increases in traffic volume. The pattern for different increase in traffic is the same when percentage of façades exposed is plotted against noise exposure level (Figure 23). Differences seems to be largest between 50 and 55 dB(A).

Table 14: Changes in mean noise exposure at the façades inside the small study area with different levels of traffic increase. Italic text marks the reference model with same factors as the main study.

Traffic increase	Lden dB(A)	Lnight dB(A)	Laeq24 dB(A)	Lmax dB(A)	Run time
Regular traffic	*43.6*	*34.9*	*40.2*	*52.3*	*7 min 30 sec*
+10%	44.0	35.3	40.6	52.3	7 min 30 sec
+20%	44.4	35.7	41.0	52.3	7 min 30 sec
+50%	45.4	36.6	41.9	52.3	7 min 30 sec

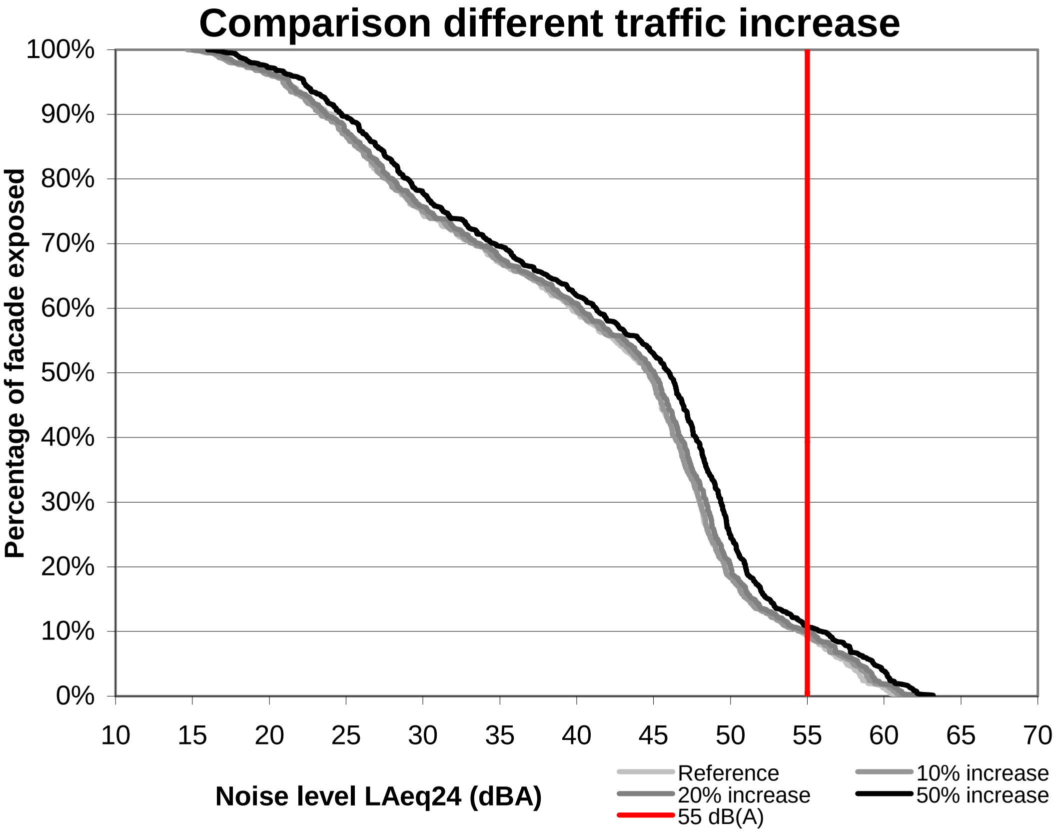

Figure 23: Percentages of exposed façades plotted against different traffic noise levels. All noise levels seem to follow a common pattern . 55 dB(A) states the Swedish threshold value.

Reflections

The differences in noise levels when using one or three reflections are small (Table 15). The differences are larger between using one and zero reflections, than between using one and three reflections (Figure 24).

Table 15: Changes in mean noise exposure at the façade for different number of reflections inside the small study area with different levels of traffic increase. Italic text marks the reference run with same factors as in the main study. Italic text marks the reference model with same factors as the main study.

Reflections	**Lden dB(A)**	**Lnight dB(A)**	**Laeq24 dB(A)**	**Lmax dB(A)**	**Run time**
Singel Reflection	43.6	34.9	40.2	52.3	7 min 30 sec
0 Reflections	40.5	31.5	37.1	51.3	1 min 50 sec
3 Reflections	44.0	35.3	40.6	52.4	39 min 25 sec

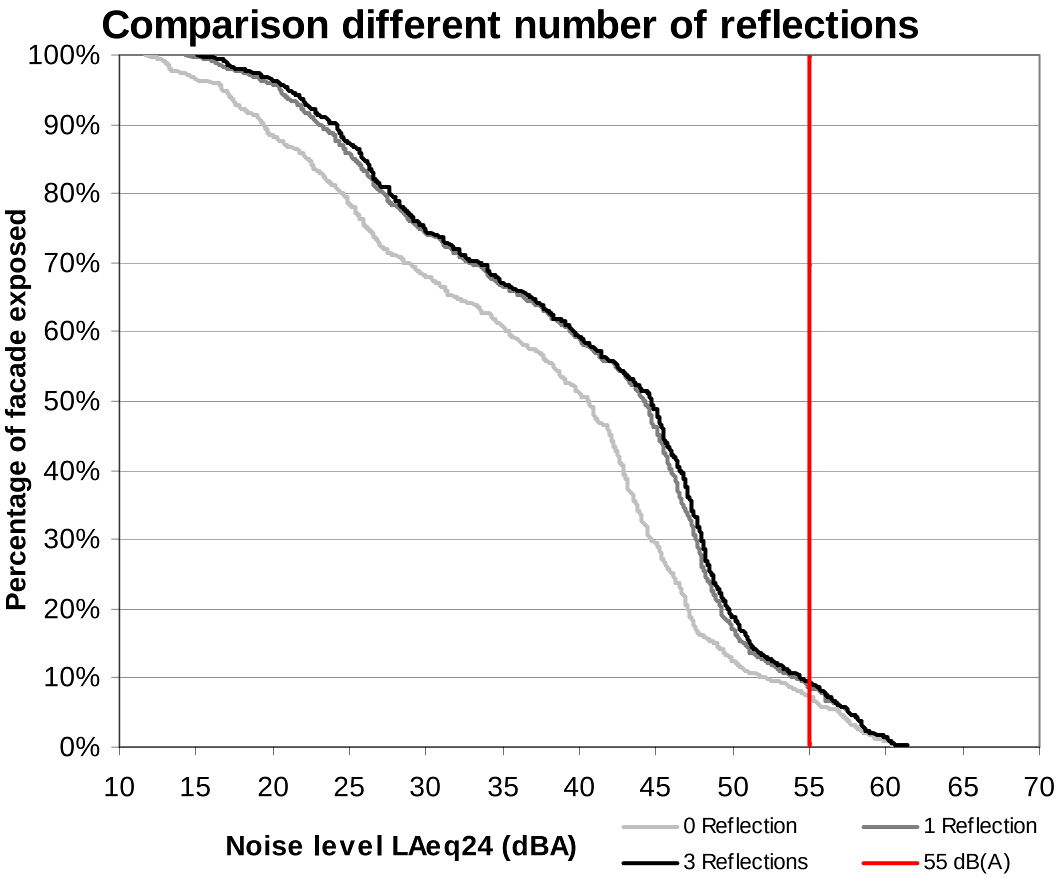

Figure 24: Percentage of façades exposed versus different noise levels for different number of reflections. The difference between zero and one reflection is bigger then the difference between one and three reflections.

Different elevation data

The differences in mean value between using elevation from satellite or laser scanning is about 1.5 dB(A) for L_{Aeq24} and L_{den}, L_{night} (Table 16). Differences between using elevation from laser scanning or from satellite based data is largest for the decibel interval 40-50 dB(A) (Figure 25).

Table 16: Mean noise exposure for different elevation data from satellite (ASTER) or laser scanned at façades inside a small study area. Italic text marks the reference model with same factors as the main study.

Elevation	Lden dB(A)	Lnight dB(A)	Laeq24 dB(A)	Lmax dB(A)	Run time
Laser	*43.6*	*34.9*	*40.2*	*52.3*	*7 min 30 sec*
Satellite	42.1	33.4	38.7	51.7	1 min 31 sec

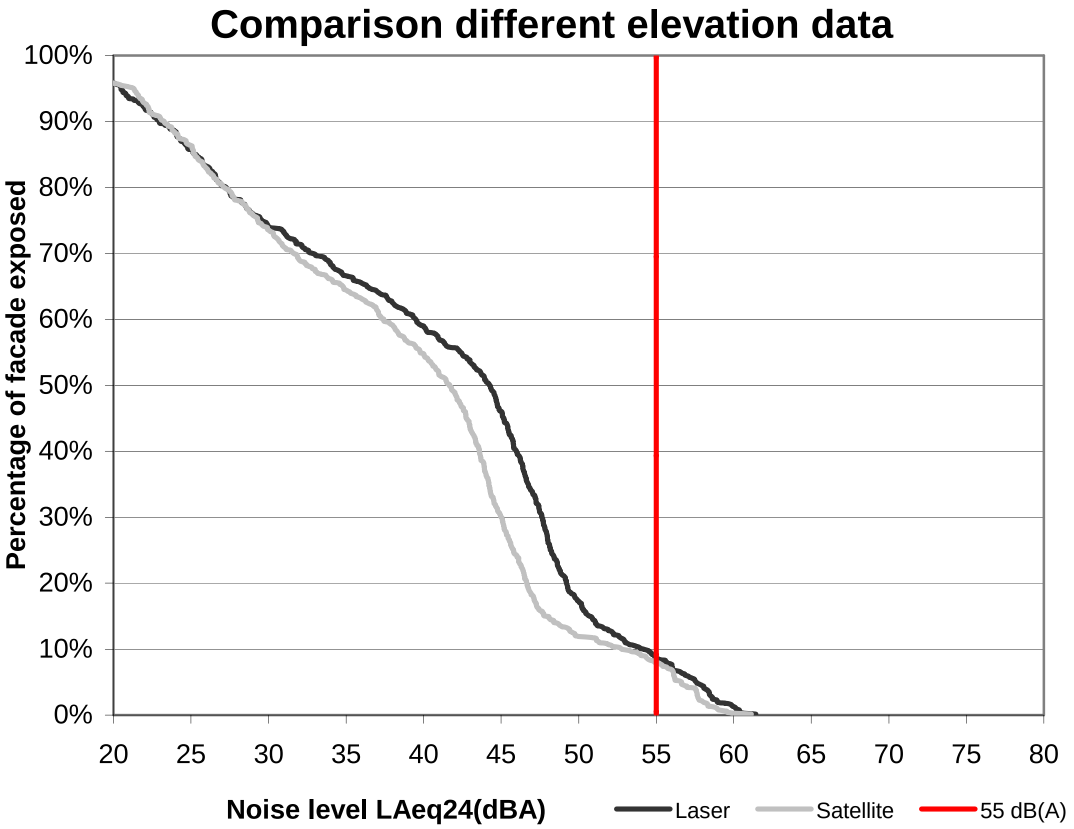

Figure 25: Percentage of exposed façades plotted against noise levels from laser scanned elevation data and satellite elevation data.

For results from more factors comparisons, see Appendix I.

6. Discussion

6.1 Modelled Noise Exposure in Burlöv

In the results modelled noise is presented for both 300 m and 1000 m search radii. The results using a 300 m search radius acts as a reference run for which the uncertainty in the calculation method is better known (3-5 dB(A); Jonasson *et al.* 1996). The calculation with a 1000 m search radius is probably more representative due to that sources on a longer distance than 300 m are included (Jonasson and Gustafsson 2010). In directions from the Swedish EPA Jonasson & Gustafsson (2010) suggest the use of a search radius between 1500-3000 m. Burlöv has a number of highly trafficked roads that affects noise exposure over long distance. All individuals in Burlöv are affected by at least one highly trafficked road when using a search radius of 1000 m. The discussion will therefore focus on the results using 1000 m search radius when comparing to former studies.

The maximal exposure ($L_{AF\max}$) in this study is almost exactly the same using a 300 m and a 1000 m search radius. When calculating $L_{AF\max}$ the decrease of sound is 6 dB(A) due to a doubling of the distance, compared to 3 dB(A) when calculating the equivalent noise exposure (Jonasson *et al.* 1996). This means a fast reduction of noise due to distance. This shows that no sources in Burlöv´s municipality are stronger at longer distances than 300 m than within, concerning maximal noise levels. There are 6 out of 16166 persons that are exposed to slightly higher maximal noise levels using a 300 m search radius. This is most probably because of the small uncertainty within the software SoundPLAN.

In comparison the difference in exposure between the three equivalent noise measures ($L_{Aeq,24h}, L_{den}, L_{night}$) using 300 m and 1000 m search radii follow the same pattern (Figures 18-20). There are small differences at higher exposure and larger differences at lower exposure. Basically there are no differences (0.02 dB(A)) to the highest exposed person, but there are differences to the lowest exposed (Tables 2, 4 and 6). The small differences in the results over 60-65 dB(A) using a 300 m search radius instead of 1000 m search radius, imply that it is possible to calculate highly exposed persons in Burlöv using a shorter search radius. The selected search radius will be further discussed later on.

The modelled noise exposure from $L_{Aeq,24h}$ in Burlöv is higher in this study (31.9% >55 dB(A) using a 1000 m search radius) compared to former studies (15.5 % ;Simonsson 2009, 4%; Appelberg 2009). One probable explanation is that this study is detailed and focuses on Burlöv´s municipality. The purpose of Simonsson´s (2009) study was to calculate noise in all of Sweden and in Appelberg´s (2009) all of Scania. Consideration was paid to more factors in this study compared to the two others. One example of the differences was that noise was calculated at 4 m height in this study and on 2 m height in Simonsson (2009) and Appelberg (2009). Mattisson (2011) show that exposure from road noise is lower at 2 m than 4 m in Burlöv municipality, due to greater screening from buildings and topography. Even so this is only one reason for the differences.

According to the Swedish thresholds the maximum level at a patio in connection to the residence should not exceed 70 dB(A). In this study the percentage of persons exposed to $L_{AF\max}$ > 70 dB(A) at the highest exposed façade was 51.9 %. This is well above the average noise exposure of $L_{AF\max}$ at 37 % in Scania according to Björk *et al.* (2006). The World Health Organization recommends an even lower maximum exposure ($L_{AF\max}$) outside bedroom façades with a threshold value at 60 dB(A). In this study 85.4 % of the population exceeds this threshold.

The higher noise exposure in this study corresponds better to the experienced noise level in Burlöv municipality according to a report concerning people's health made by Region Scania in 2008 (Albin & Bodin 2010). They found out that 35.6 % of the population in Burlöv experienced themselves as disturbed by noise.

Differences in the result of noise exposure in Burlöv between this study and former studies covering large areas, such as Scania or Sweden, indicate that it is important to make more detailed noise modelling over specific areas. This applies especially if the experienced disturbance from noise is higher in comparison to the modelled noise exposure.

Burlöv is a suburb-municipality to Malmö with heavy infrastructure, both concerning roads and railroads. Noise is often seen as a large city problem but the closeness to Malmö makes Burlöv in heritage the problem. Compared to the results of a detailed noise mapping of noise from roads in Malmö 2007, according to the END-directive (2002/49/EG), the number of exposed persons of L_{den} is lower in Burlöv with 50.6 % compared to 75.4% in Malmö (Appelberg 2007). But compared to studies made in Stockholm with 34.0 % exposed (Hallberg, Simonsson & McConnachie 2007) and Göteborg 42.8 % exposed (Hammarlund 2007), Burlöv has a higher percentage of exposed persons. Appelberg (2007) also says that a mistake in the Malmö study caused an overestimation with average 3 dB(A), due to inclusion of reflection in the own façades. This implies that Burlövs municipality has noise levels in parity with the largest cities in Sweden, which is notably because road noise is considered to be a large-city problem.

L_{night} is the noise measure that has the lowest exposure of noise from road traffic in this study. Night time exposure in Burlöv for L_{night}>55 dB(A) is 9.2 % of the population, which is about the same as for Stockholm (9.8 %;Hallberg, Simonsson & McConnachie 2007) and Göteborg (10.5 %;Hammarlund 2007). The lower L_{night} exposure in Burlöv compared to L_{den}, in relation to Stockholm and Göteborg, is probably due to less traffic at motorways than in cities at night and Burlöv´s municipality is more characterized of motorways. Even so the noise is considered to be more disturbing at nighttime and more than 6 out of 10 in Burlöv are exposed to the recommended threshold of L_{night}>45 dB(A) from WHO (Berglund, Lindvall and Schwela 1999).

Area exposure of noise from roads was separately calculated in grid noise calculations. The grid noise maps with noise exposure with different measures

(Appendix H) show the spatial pattern of the noise exposure in Burlöv. Noise levels are highest in the northern parts of the municipality, around the population centers Arlöv and Åkarp, and in the southern parts where not many people live. More than half (50.9 %) of the area of Burlöv is exposed to levels for $L_{Aeq,24h}$ over 55 dB(A) (41.2 % using 300 m search radius), which is a very large part of the population in the municipality.

6.2 Methods and Factors

Modelling noise results in very heavy calculations, when detailed data is used and consideration is paid to many factors. This is especially a problem if noise is modelled over a large area. This problem can be solved by increased calculation capacity or by simplifications of data and method. In this study the computer capacity was limited and some simplifications were therefore made for example limitation of search radius, filtering of the elevation data, only calculating noise exposure at residential buildings and limiting the number of reflections. Even so the final noise calculation took about 1 day and 5 hours (using a 1000 m search radius). Using the same method at all of Scania would result in a calculation time of about 85 days, based on the number of inhabitants in Scania in relation to Burlöv and using a similar computer capacity. To avoid errors in the borders of the calculation area (Burlöv municipalities borders), due to a search radius stretching outside the border, a buffer zone of 300 m were used around the calculation area were data about roads, buildings, elevation and so on were included.

Single factors, such as detail level of data, number of reflections and length of search radius, can have large impact on the results. It is therefore important to carefully consider each factor and document the choices to enable the reader to interpret the results.

The speed limits used in the study were stated limits not actual speed, and probably an underestimation. It would have been preferable to use measured speed of the vehicles, but that would have been very time consuming to obtain. One way to improve the results would have been to estimate the real speed instead of using speed limits. The method to collect and the actuality of the traffic intensity of the roads varied in the data set (Appendix B Figure B2-B3). Jonasson (2009) estimate the uncertainty in the model to 0.5 dB(A) per 10 % error in ADT, 1 dB(A) per 10 % error in speed and 1 dB(A) per 20 % part of heavy vehicles. It is hard to estimate the size of error because of this, but much of the estimation of the ADT was made on low speed limits and most measured values were made on the large roads. The large roads are contributing more to the noise exposure than the smaller roads, and the influence of error because of this should therefore be a small underestimation of noise exposure.

A report from New Zealand state that it is important to take the surface of the road into consideration when modelling the noise from roads: surface effect might affect the result with up to 8 dB (Kvatch & Dravitzci 2007). The possibility to do so was investigated, but no detailed information about the surface of the road could be found. There might also be a rather large effect on the noise emitted from a road depending on if the road surface is wet or dry. According to a report from the Swedish TA wet road surfaces can cause an increase of noise emission with up to 5 dB (Sandberg 2000).

According to Jonasson (2009) hardness of the ground strongly affects the result when modelling noise exposure. RTN (Jonasson *et al.*1996) differentiates between hard and soft ground and makes different corrections. The typical uncertainty varies between 0-9 dB(A) for hard or soft ground (Jonasson 2009). The classification of ground into hard and soft varies between former studies, Kujala (2002) classify all industrial area to hard ground and the rest to soft, Appelberg (2007) classify the city core as hard and the rest as soft and Hammarlund (2007) classify lakes and ocean as hard and everything else as soft. In this study impedance from a land use classification was used, this made it possible to better distinguish between what was soft and hard ground (Sohlman *et al.* 2004).

Another important factor when modelling the propagation of noise is the terrain. The terrain may act as a barrier and may therefore have large influence on the noise propagation. It is important to have as detailed elevation data as possible. In earlier large-scale investigations the equidistance varies between 0.5 m or better up to 10 m equidistance (Jonasson 2009). Jonasson (2009) says that different elevation data can cause uncertainty with 0-6 dB(A). In this study very high-resolution data from laser scanning was used, errors depending on topography are therefore estimated as low in this investigation. While the elevation data was so detailed noise protection banks where included in the modelling through the topography. The low equidistance made it possible to make corrections for this without special digitizing of the noise protection banks.

The height of the buildings was calculated, based on a DSM and a DTM, and can be considered as detailed (Jonasson & Gustafsson 2010). Even if a template height is assigned to different types of buildings the uncertainty due to this can be considered as low (Jonasson 2009).

Noise exposure was connected to population data through connection to the closest residential building. A real estate could have more than one building and it is therefore possible that the population point was connected to the wrong building (Figure 26). This is considered to be a good way of connecting exposure and population data even if connection via address is the most accurate (Jonasson 2009). The façades with the highest noise level was used to represent the whole building, this means a systematic overestimation of the noise exposure. This overestimation is smaller in villa areas and larger in bigger houses (Jonasson 2009). Burlöv´s municipality has both villas and larger houses, so the uncertainty depending on this is spatially unevenly distributed. There is a possible source of error because of the classification of residential buildings that was done. It is possible that some buildings were wrongly classified. But there probably would have been a much larger error if no classification had been made, because of connection of persons to garages and outhouses.

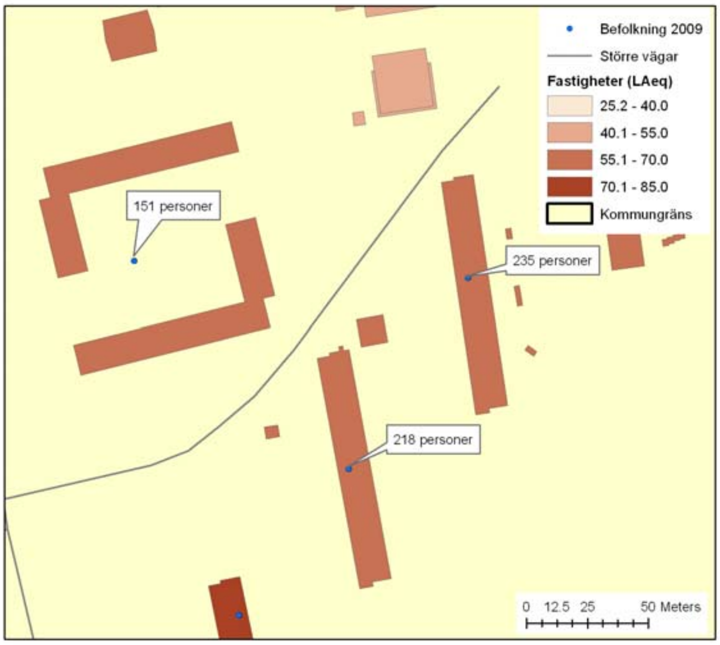

Figure 26: Population data was given as a point in the middle of the real estate for each person. Sometimes a real estate have more than one building, to which the population point should be connected to. This may cause that a population point is connected to the wrong building.

The reason why RTN was used in this study and not Nord2000 or Harmonise is because this is the standard method in Sweden at the moment. There is an ongoing process to change method that has started but it is not known if Nord2000 or Harmonise will be the next standard method, even if it looks like it will be Nord2000. Nord2000 have not yet been fully tested in for example the software SoundPLAN, which means that the noise modeller would need to have great experience in noise modelling to notice errors due to the software.

All receivers where calculated at 4 m height according to the END-directive (2002/42/EG). This means that all persons in a building were assumed to be living on 4 m height. A better estimation of the sound exposure level could be made if noise levels were calculated for all floors of the residential buildings. Information about where in a building a person lives is unfortunately not available. But there is at the moment an ongoing project in Sweden where this information is collected and enables the possibility to an even better connection of noise exposure to persons. Receivers can also be placed at evenly space along the façades to improve the results, but this will increase the complexity and calculation time.

6.3 Sensitivity analysis

The sensitivity analysis shows how different factors influence the noise exposure in a small area of Burlöv (Appendix G). This small area was picked to be representative for all of Burlöv and by that give an indication of the importance of different factors. The area is rather flat, has villa buildings and is close to highly trafficked roads. The factor that showed largest difference in noise exposure was search radius. An increase of a shorter search radius stronger influenced the result than an increase of a longer search radius. The influence of an increasing search radius gets smaller with a longer search radius because the noise losses energy with increasing distance. The increase in mean value between a 500 m and a 1000 m search radius for L_{den} was 2.6 dB(A) and

0.9 dB(A) between 1000 m and 2000 m search radii. This shows that it would be preferable to use a 2000 m search radius or even longer due to that sources at these distance seems to have a rather large influence on the results. In this study a shorter search radius was selected due to limited computer capacity. In the small search area the calculation time was almost tripled when increasing from 1000 m to 2000 m search radius. Increasing traffic causes an increase of 0.4 dB(A) on the noise exposure per 10% increase in traffic intensity, this corresponds well to the estimated increase of 0.5 dB(A) from Jonasson (2009), who tested RTN on mission from the Swedish EPA. The average difference between using zero and one reflections for L_{den} was 3 dB(A), which should be considered as a very large influence. The average difference between using three and one reflection is 0.4 dB(A), which is relative small. Differences because of the number of included reflections are dependent on how complex the landscape is, with larger differences inside than outside cities (Jonasson *et al.* 1996). Two different sources of elevation data were tested, one with satellite data (30 m resolution) and one with laser scanned data with one measure point for every square meter. The difference in the average noise exposure was 1.5 dB(A) higher, when using laser scanned elevation. This can probably be explained by differences in height between sources and receivers for the two elevation models. The elevations of the road surfaces were included in the laser scanned data, due to more detailed data, and are a possible explanation to the higher noise exposure. Laser scanned data is considered to be more accurate (Jonasson and Gustafsson 2010) and was therefore selected in the study, even in the calculation time was much longer than for the satellite based data.

6.4 Uncertainties and possible improvements

It is hard to estimate the collected uncertainty in this study, but the possible corrections according to the calculation method has been followed in large part. The sensitivity analysis was made to quantify some of the uncertainties in the analysis. Generally there are a number of steps in noise modelling that can generate uncertainty. Four possible sources of errors are:

Calculation method – Is the theoretical or mathematical method. Research has shown differences of up to 15 dB between different National European calculation methods (Nijland and van Wee 2005). The accuracy of RTN, used in this study, compared to measured values has a standard deviation of 3-5 dB(A), depending on the distance from the source (Jonasson *et al.* 1996).

Software – To be able to fully use the calculation method it needs to be implemented in software. There is different software that can be used to implement the calculation methods. Some of them are specific for noise modelling such as SoundPLAN and CadnA, while others are general GIS-software such as ArcGIS. If detailed modelling should be applied it is recommended to use specific software to keep calculation time as short as possible. According to the producer RTN has been implemented in SoundPLAN with an accuracy of ± 0.2 dB (SoundPLAN Help Manual 2010).

Data – Depending on the accuracy of the data in the noise model the uncertainty varies. The sensitivity analysis shows some the variations when using different types of data. This uncertainty of different data, concerning RTN, has been investigated by

Jonasson (2009), who for example found out that topography can have an influence of 0-6 dB(A).

User application – Even if the same software, data and calculation method is used there are a number of decisions that need to be made by the noise modeler, for example the placement of receivers, search radius and number of reflections. A study made with the Dutch national calculation method showed differences with up to 6 dB due to different interpretations made by three noise modelers (Nijland and van Wee 2005).

A rather course information about the borders of Burlöv municipality was used, it would have been better to use more detailed information. Basic data originated from different years. Buildings are from 2004, laser scanned elevation from 2008, ground softness from 2006, noise walls from 2010 and traffic intensity from 2010. It would have been preferable to have all data from 2010, but this was not available. Even so, data is relatively new and can be considered to represent conditions 2010 in a good way.

Jonasson and Gustafson (2010) have released directions on how to model noise in accordance to the END-directive (2002/49/EG). In this report they classify the accuracy when using different types of quality on different factors. Class A is the best, class B the minimum to action plans, class C the minimum level to fulfil noise modelling in accordance with the END-directive and class D is the lowest and not recommended. According to this classification a majority of the factors in this study is classified in class A or B. Ground softness and elevation, which both are considered to be very important factors, are for example classified in class A. The number of reflections and traffic information are example of factors that are classified in class B and the calculation height and the distance between receivers are in class C. According to Jonasson (2009) calculation height can influence the result with 0-1 dB(A) and the placement of calculation points with 0-3 dB(A). It is hard to give the total numerical uncertainty of the calculation (Jonasson & Gustafsson 2010), but according to this report the accuracy in this noise model is high. The quality of data in this study is high compared to many other studies (Simonsson 2009; Appelberg 2009).

Even though a large effort has been put in finding as detailed data as possible and make the right choices in the method it is important to critically interpret the results, while this is a model of the reality. The threshold value for L_{Aeq24} is 55 dB(A). A large number of persons, about 5700, where exposed to L_{Aeq24} levels between 50-60 dB(A). This means that a systematically over- or underestimation can have a large impact on the number of persons exceeding a threshold value.

The calculation method sets the limit for which factors that is possible to include. Some of these factors are more important than others such as the ground softness, topography, search radius and traffic data. It is important to carefully consider these factors and try to get the best available data and make test calculations to find the best way to include them. Noise modelling is very complex and it is therefore important to document the method well to enable the reader to understand the uncertainty. In this study noise has been modelled on a detailed level for Burlöv´s municipality. The results show that a large percentage of the population are exposed to high levels of noise both concerning equivalent noise levels (31.8 % L_{Aeq24} >55 dB(A)) and maximal noise levels (51.9 % $L_{AF\max}$>70 dB(A)). The problem is especially large during night time where more than 6 out of 10 are exposed over recommended levels (>45dB(A)). The modelled levels in this study imply that the noise from roads is a large problem in Burlöv´s municipality.

7. Conclusions

- According to this study almost one third of the population (31.9 %) in Burlöv´s municipality is exposed to equivalent noise levels ($L_{Aeq,24h}$) over 55 dB(A) at 4 m height. This is a higher exposure than found in former studies and better corresponds to the experienced noise disturbances in the municipality.

- According to this study 6 out of 10 in Burlöv municipality are exposed to nighttime noise (L_{night}) over 45 dB(A), which is a recommended threshold from WHO.

- A large number of persons are exposed to noise levels close to threshold values. This makes a possible systematic error of the noise exposure levels having a large impact on the number of persons exceeding the threshold values.

- The number of persons exposed to noise levels over threshold values is higher in this study in comparison to former large scale studies including Burlöv municipality. This shows that it might be important to model noise on a detailed scale when looking at a specific area.

- The modelled noise levels in Burlöv municipality are in the same order as noise levels from road traffic in the three largest cities in Sweden (Malmö, Göteborg and Stockholm).

- Single factors can have large influence on the results in noise modelling. It is therefore important that careful consideration is paid to each factor and the choices well documented to enable a good interpretation of the results.

- The search radius is strongly affecting the result of noise modelling. A longer search radius often includes more sources and results in higher noise exposure.

- Other important factors when modelling noise is topography, ground softness, reflections, placement of receivers and road data.

- Noise modelling is very computationally demanding, when detailed data is used and considerations are paid to many possible corrections. This problem can be solved through increased computer capacity or simplifications in the data and method.

8. Future Research

One way to improve the results of the noise exposure calculation would be to use a more detailed calculation method. At the moment RTN is the standard calculation method in Sweden. But a more detailed method like Nord 2000 or Harmonise could give better results due to consideration of more factors (Jonasson *et al.* 2010). Meteorology is such a variable that is important to the propagation of noise (Mattsson *et al.* 2009). More detailed data would also increase the accuracy of noise modelling. Traffic distribution on municipality roads is for instance data that usually has high uncertainty.

Even if road traffic are considered to be the most important sources of noise in many cases, it is important to take other sources of noise into account. Consideration to other sources such as noise from railroads, aircrafts and industries would give a better picture of the total noise exposure and would be a way of elucidate the problem with noise in Burlöv municipality (Mattisson 2011). Even so, it is hard to add the noise from different sources because equally large noise from different sources causes variable size of disturbance (Sjöberg 2005).

The noise measures that have been used in this study measure the equivalent or the maximal noise level. This mean that the character of the noise is not described. One way to show this could have been to count the number of disturbances. In this study noise is calculated in the home environment, it would have been interesting to follow persons through the day and model noise also at for example their working places.

The results from this study could for example be used to connect health related problems to noise exposure, such as the use of pharmacies or heart and vessel diseases.

It is very hard to compare the results of noise modelling when different methods have been used. In future research the optimal would be that all noise modelling in Sweden, EU or even the world was done with the same method and considerations, then the results would be more comparable. To improve knowledge about noise and the effect it has on the society noise modelling should be conducted on all municipalities in Sweden with standardize methods and connected to health effects.

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Svensson Jonny (2010), Project employeed landscape architect, Burlöv Municipality, Oral communication: 2010, jonny.svensson@burlov.se

Appendix A – Table of data

Table A1: This table contains information about the data that were used in the noise model. All data were used in the main model of noise except for satellite elevation, which were only been used in the sensitivity analysis.

Type of data	Coordinate system	Format	Source	Contact
Roads (including heavy/light vehicles distribution, number of lanes, speed, width)	RT90 2,5 gon W	Polyline (shp)	Skånes luftvårds förbund	Lotten Jönsson, Malmö municipality, lotten.jonsson-johansson@malmo.se
Buildings	RT90 2,5 gon W	Polygon (shp)	Skåne kartan (Geodatacenter skåne AB)	Department of Earth and Ecosystem Sciences, Lund University
Laser elevation (Digital Surface Model, Digital Terrain Model and equidistance)	SWEREF 99 13 30	ASCII (DSM, DTM) Polyline (equidistance)	Burlöv´s Municipality	Kerstin Lönnhag, Burlöv Municipality, kerstin.lonnhag@burlov.se
Satellite elevation (ASTER)	WGS84/EGM96 geoid	Geotiff (Raster)	National Aeronautics and Space Administration (NASA)	NASA Homepage: https://wist.echo.nasa.gov/wist-bin/api/ims.cgi?mode=MAINSRCH&JS=1 (collected 14th March 2010)
Ground cover (Corine)	ETRS 1989 LAEA	Polygon (shp)	European Space Agency (ESA)	ESA Homepage: http://www.eea.europa.eu/themes/landuse/clc-download (collected 29th March 2010)
Noise protection walls	SWEREF 99 13 30	DXF	Burlöv´s Municipality	Jonny Svensson, Project employeed landscape architect at Burlöv Municipality jonny.svensson@burlov.se
Population data	RT90 2,5 gon W	Point (shp)	Region Skåne	Emilie Stroh, Lund University, emilie.stroh@med.lu.se

Appendix B – Roads and traffic flow in Burlöv municipality

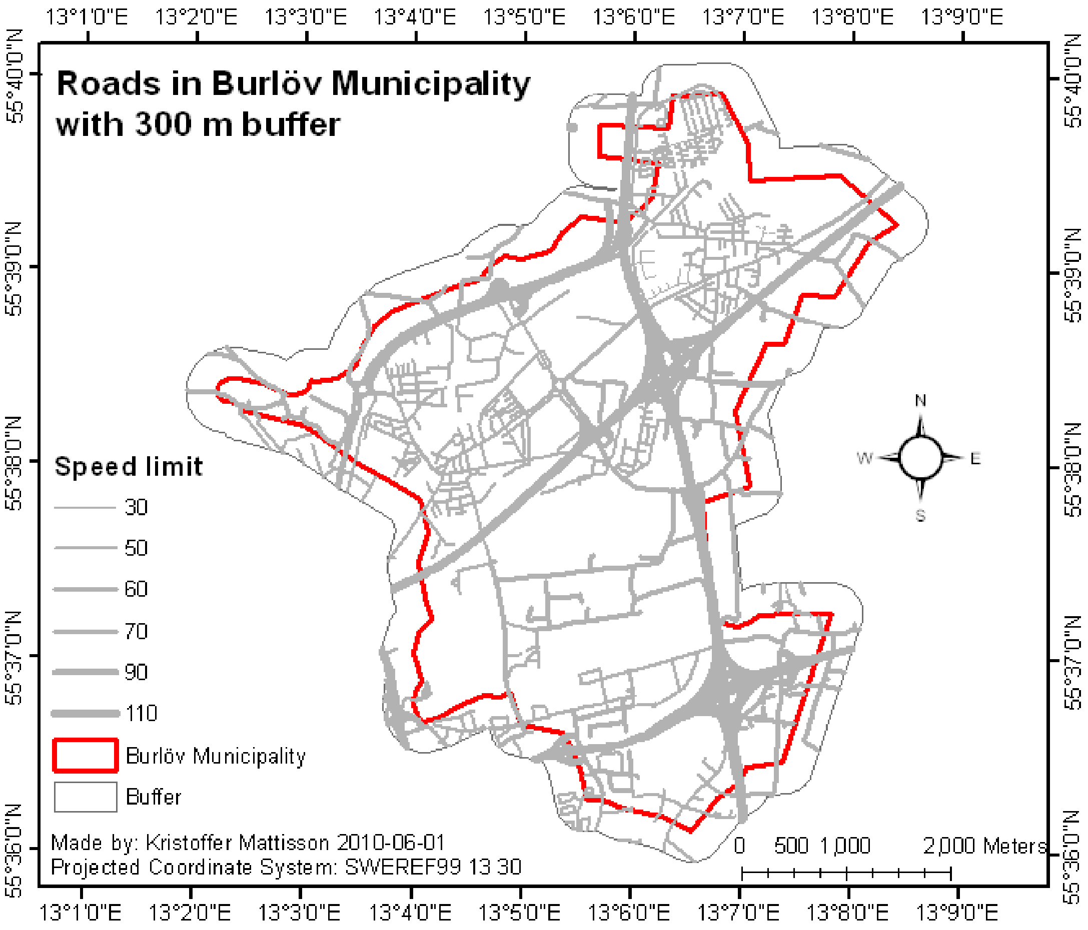


Figure B1: Distribution of roads based on speed limits in Burlöv municipality with a 300 m buffer around the municipality.

Table B1: Total length of road segments with different speed limits in Burlöv including a 300 m buffer around the municipality.

Speed limit (km/h)	Length (km)	%
30	3.8	1.7
50	94.7	43.1
60	0.5	0.2
70	52.8	24
90	13.2	6
110	54.9	25
Total	**219.9**	**100**

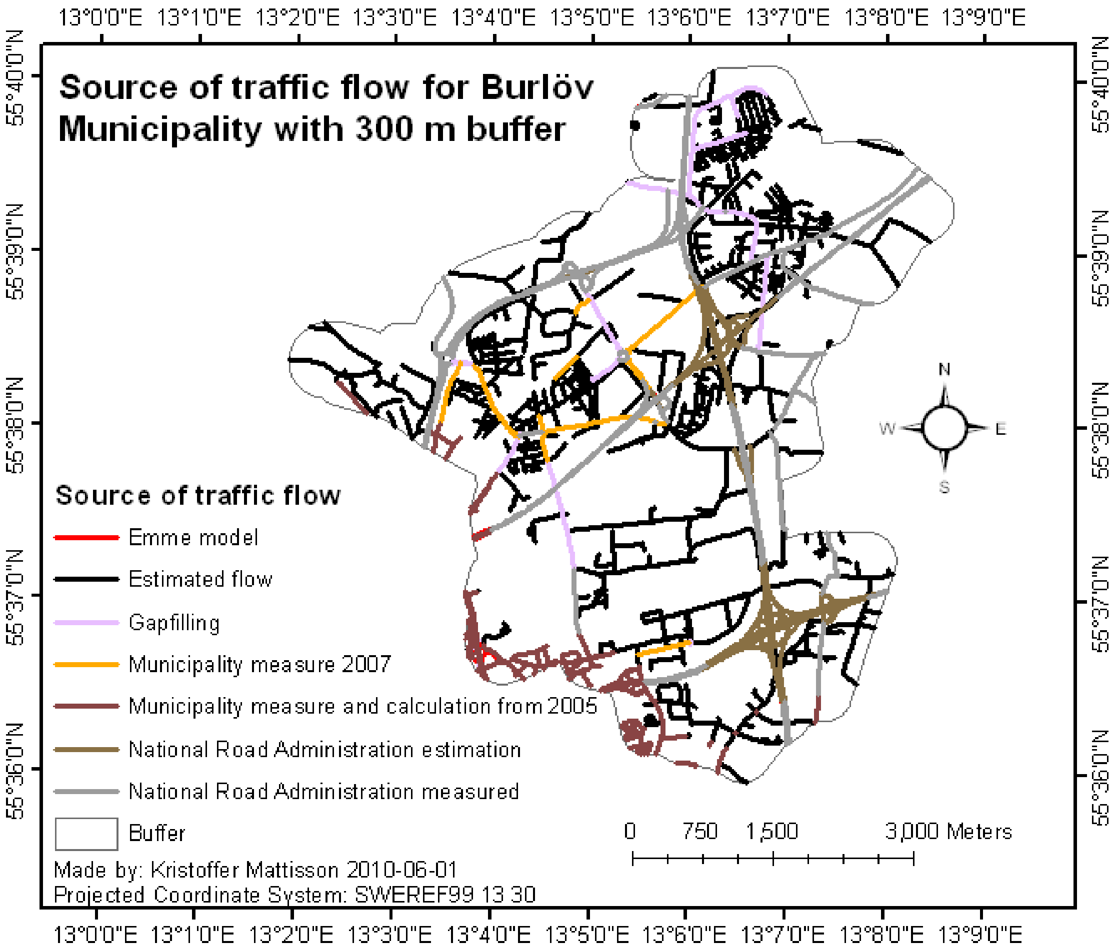


Figure B2: Source of traffic flow on the roads from all road segments in Burlöv including 300 m buffer around the municipality.

Table B2: Total length of road segments with different sources of traffic flow in Burlöv municipality including 300 buffer around the municipality.

Source of traffic flow data	**Length (km)**	**%**
Emme modelling	1.6	0.7
Estimated flow	112.9	51.3
Gapfilling	9.6	4.4
Municipality measure 2007	7.5	3.4
Municipality measure and calculation from 2005	18.2	8.3
National Road Administration estimation	27.5	12.5
National Road Administration measured	42.6	19.4
Total	**219.9**	**100.0**

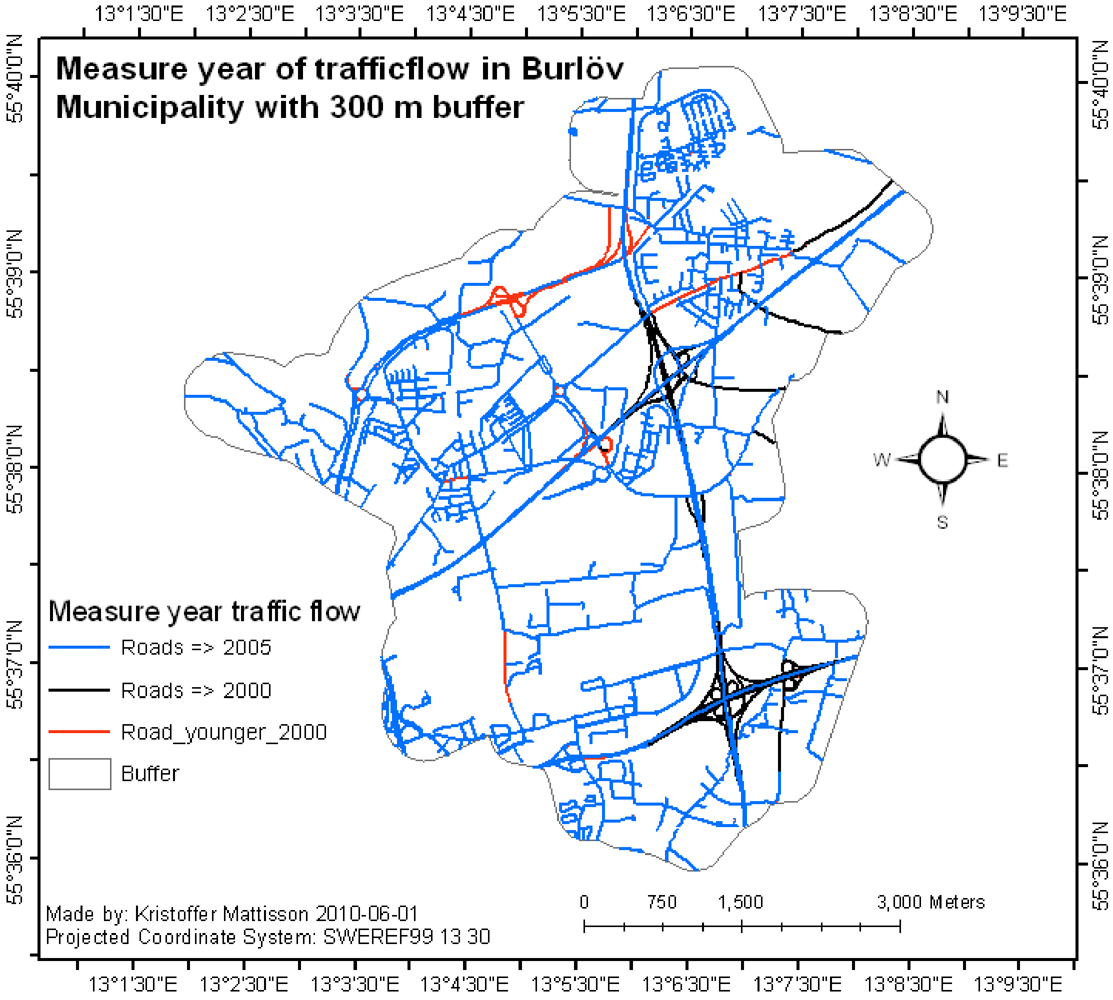


Figure B3: Year of origin of traffic flow on roads in Burlöv including a 300 m buffer around the municipality.

Table B3: Total length of road segments based on the year of origin in Burlöv including a 300 m buffer around the municipality.

Measure year	**Length (km)**	**%**
=>2005	177.8	80.9
>=2000 - 2005<	30.7	14.0
< 2000	11.4	5.1
Total	**219.9**	100.0

Appendix C – Buildings and residential buildings in Burlöv municipality

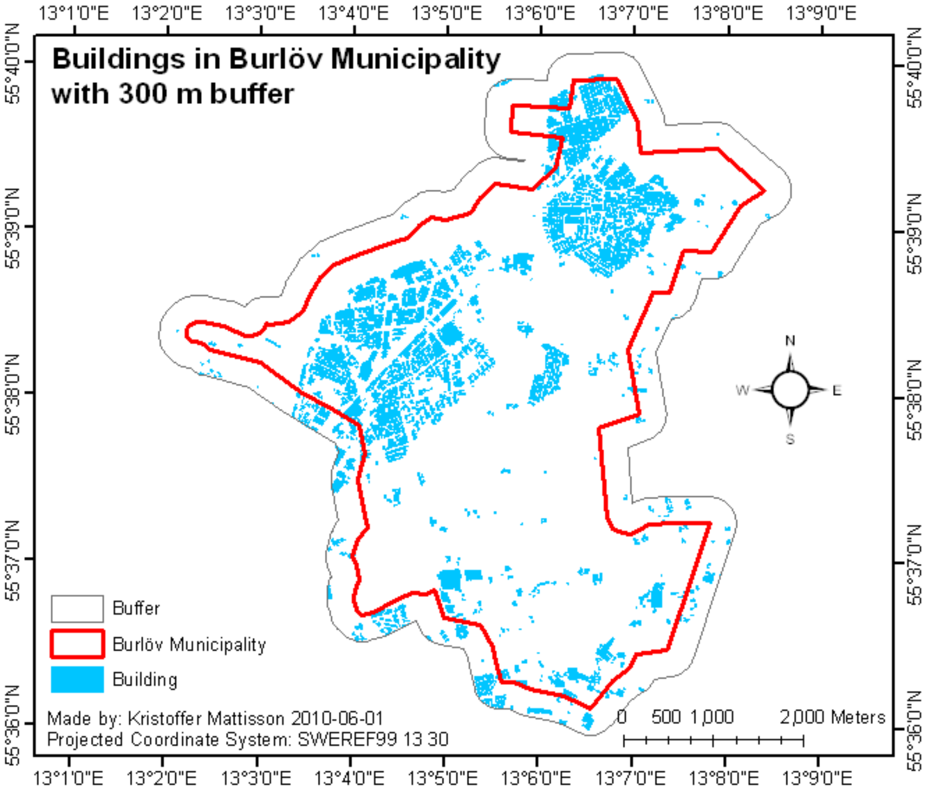


Figure C1: All buildings inside Burlöv including a 300 m buffer around the municipality.

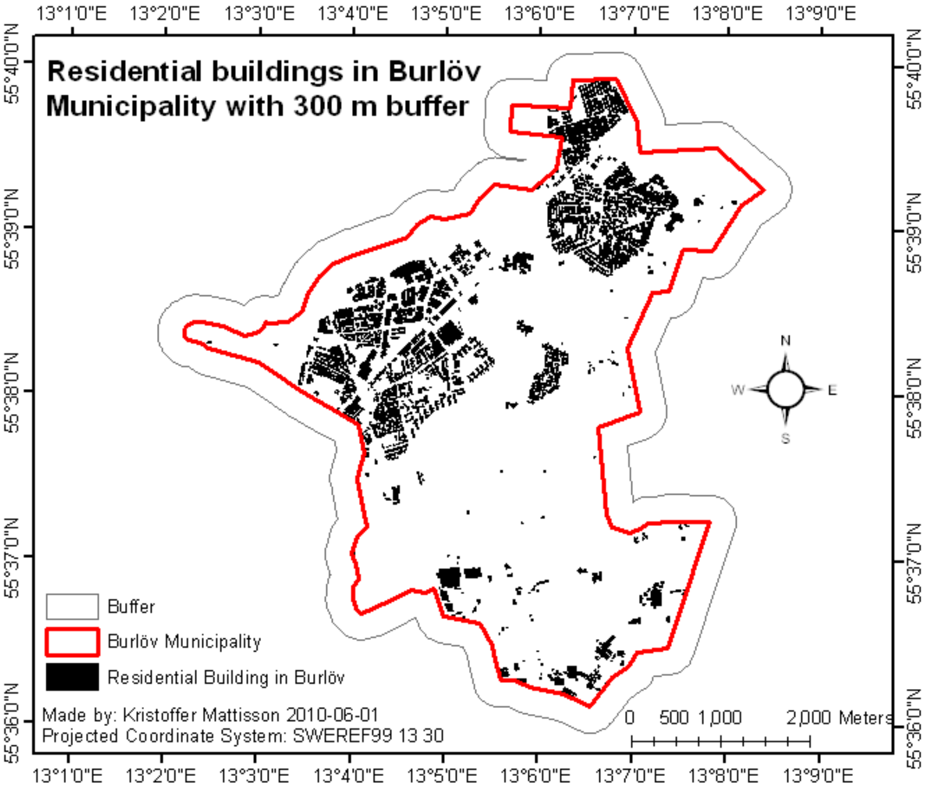


Figure C2: All residential buildings inside Burlöv including a 300 m buffer around the municipality.

Appendix D – Ground softness and impedance

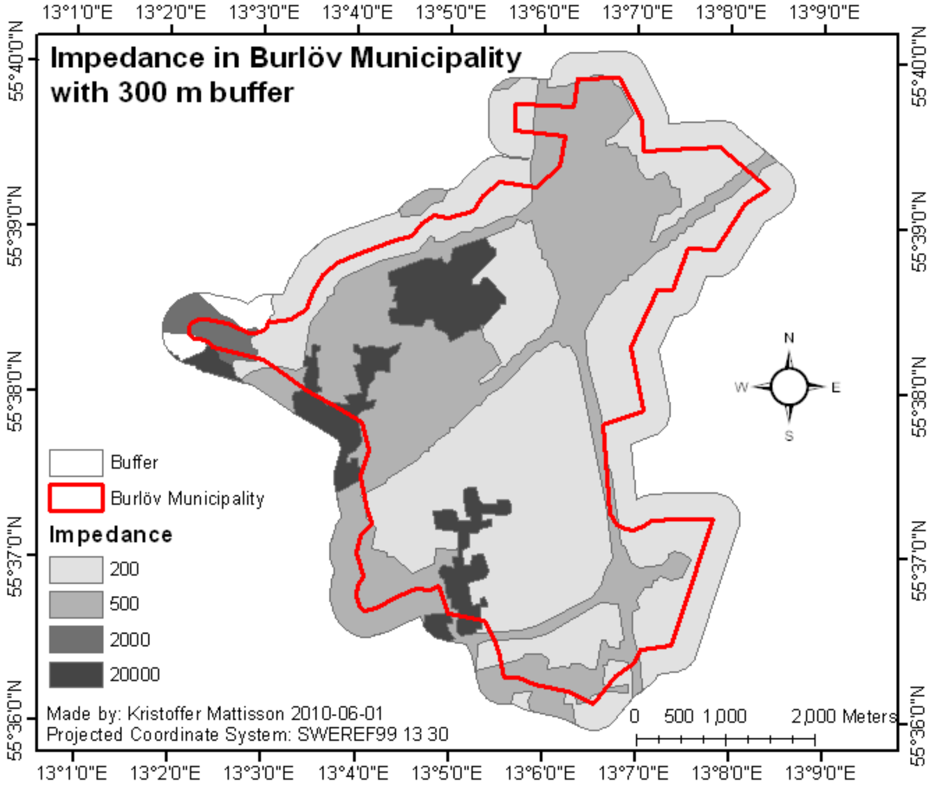


Figure D1: Ground impedance in Burlöv including a 300 m buffer around the municipality.

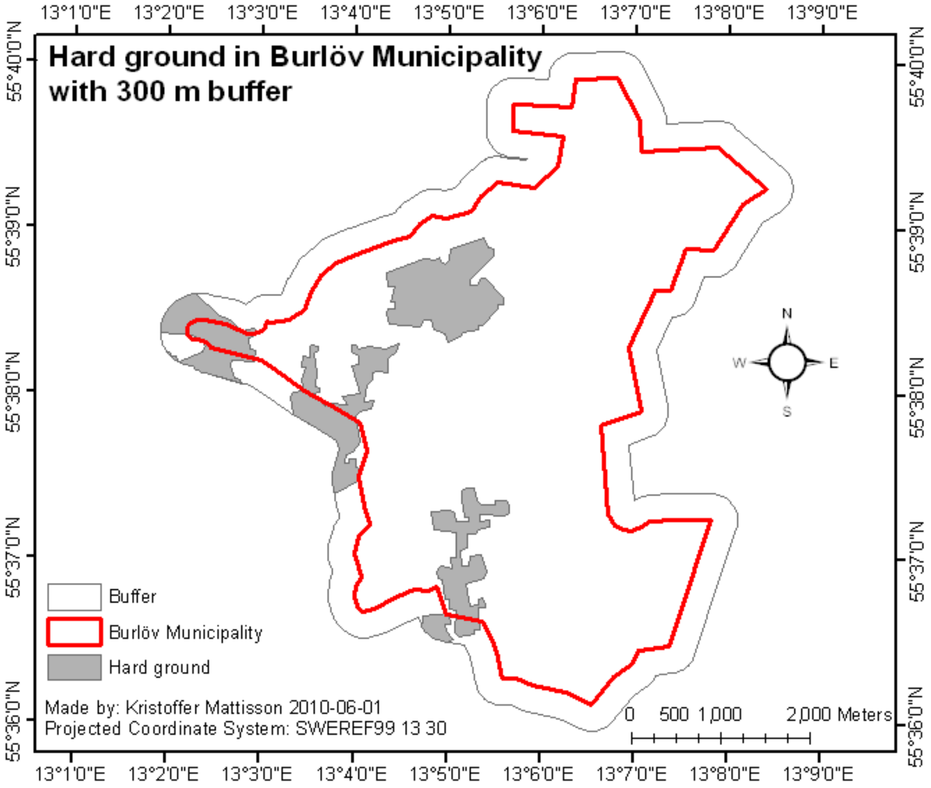


Figure D2: Hard ground classified, according to the Nordic prediction method - Road traffic noise from 1996, in Burlöv including a 300 m buffer according.

Appendix E – Noise walls in Burlöv municipality

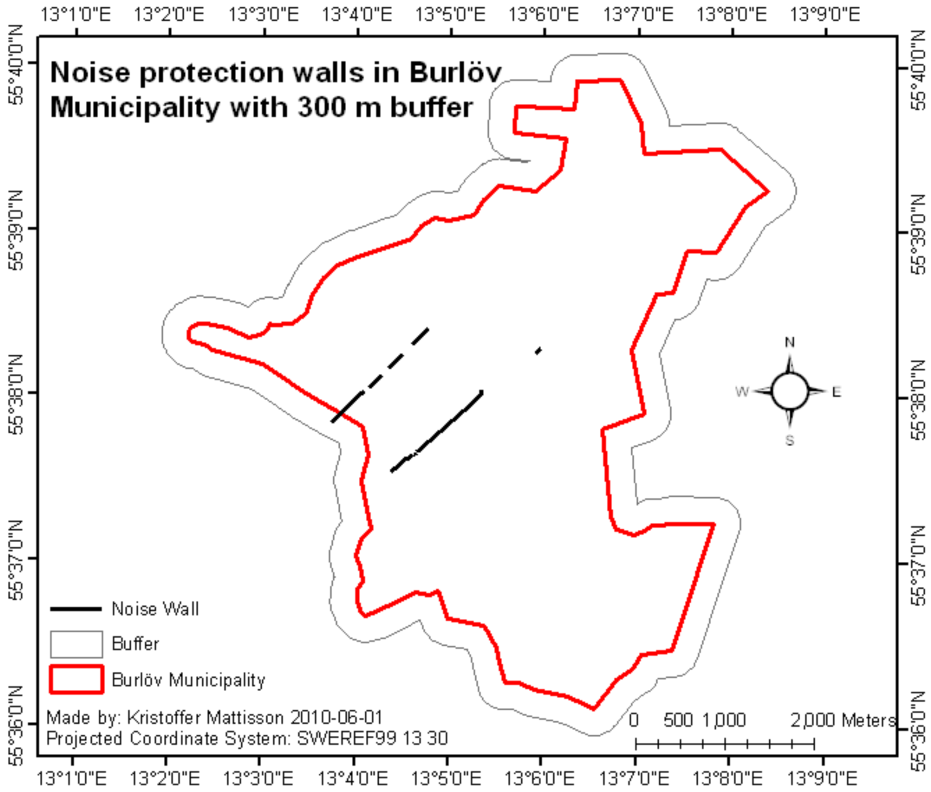
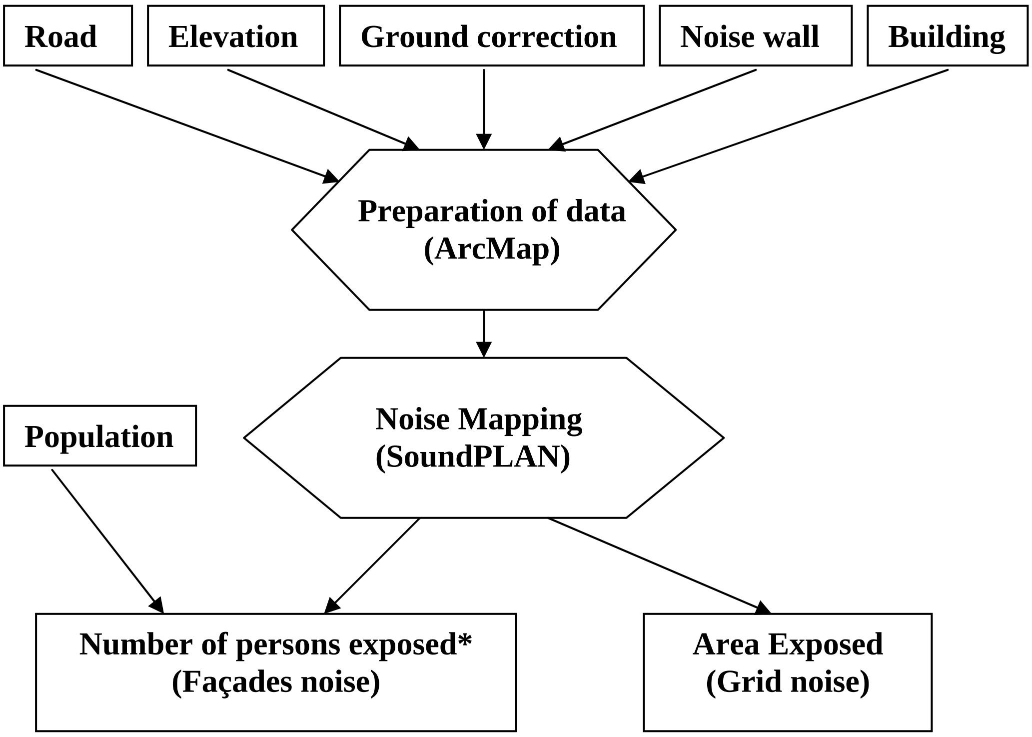


Figure E1: Noise walls in Burlöv including a 300 m buffer around the municipality.

Appendix F – Flowchart of the method to model noise in Burlöv municipality



*Partly conducted by Emilie Stroh (2010)

Figure F1: Different in data were prepared in a general GIS-software and imported to specific software to model noise. Noise levels at the façades of residential buildings were modeled and the results connected to population data. The area exposure of noise was calculated separately.

Appendix G – Study area in the sensitivity analysis

Figure G1: Study area in the sensitivity analysis of different factors.

Appendix H – Noise level maps and tables over noise from roads in Burlöv municipality

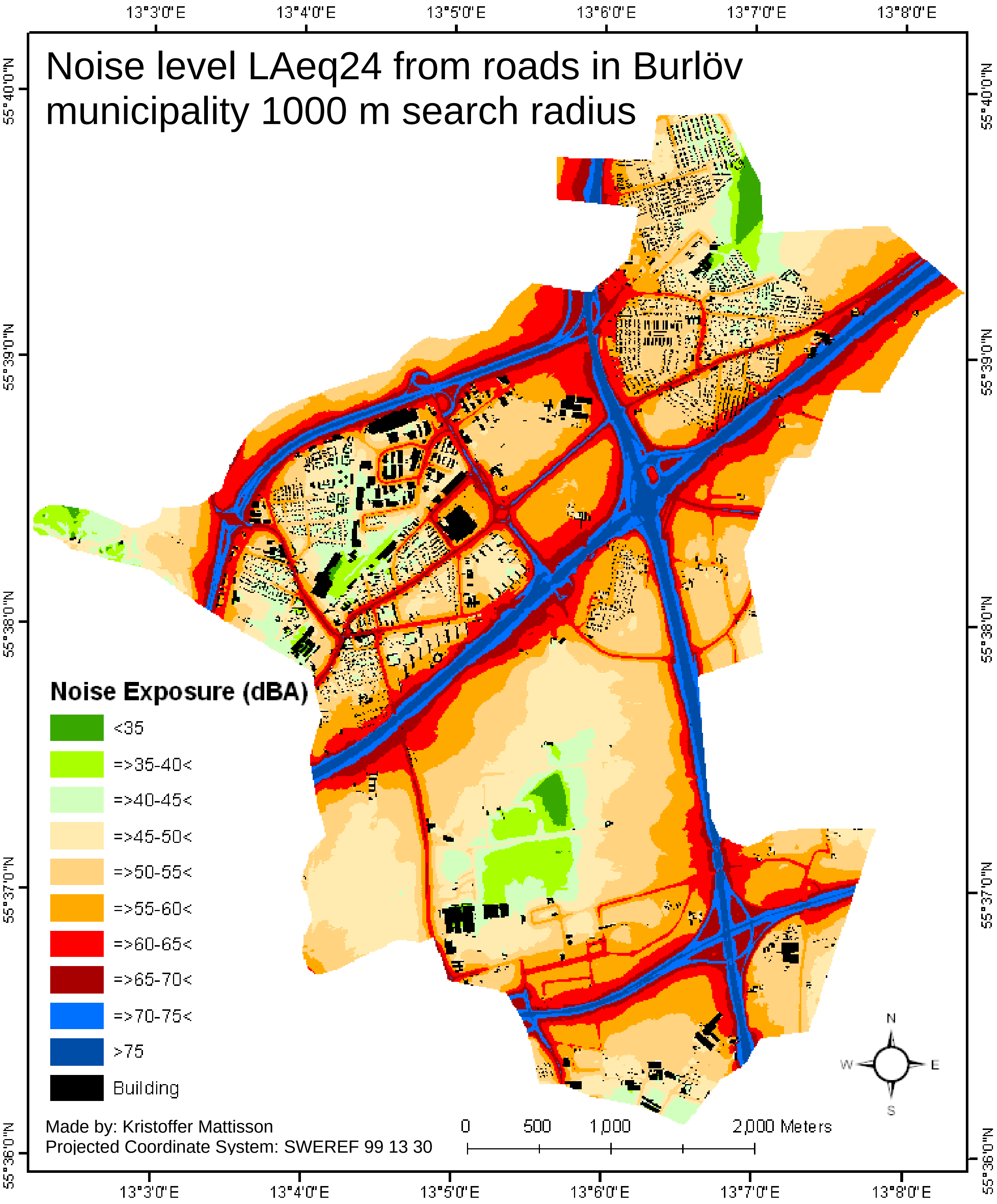


Figure H1: Area exposed to different levels of noise to the measure L_{Aeq24} at 4 m height in Burlöv municipality using 1000 m search radius. Noise has been calculated in a grid with 10 m between each calculation point. Road traffic noise – Nordic prediction method from 1996 implemented in the software SoundPLAN has been used to model the noise.

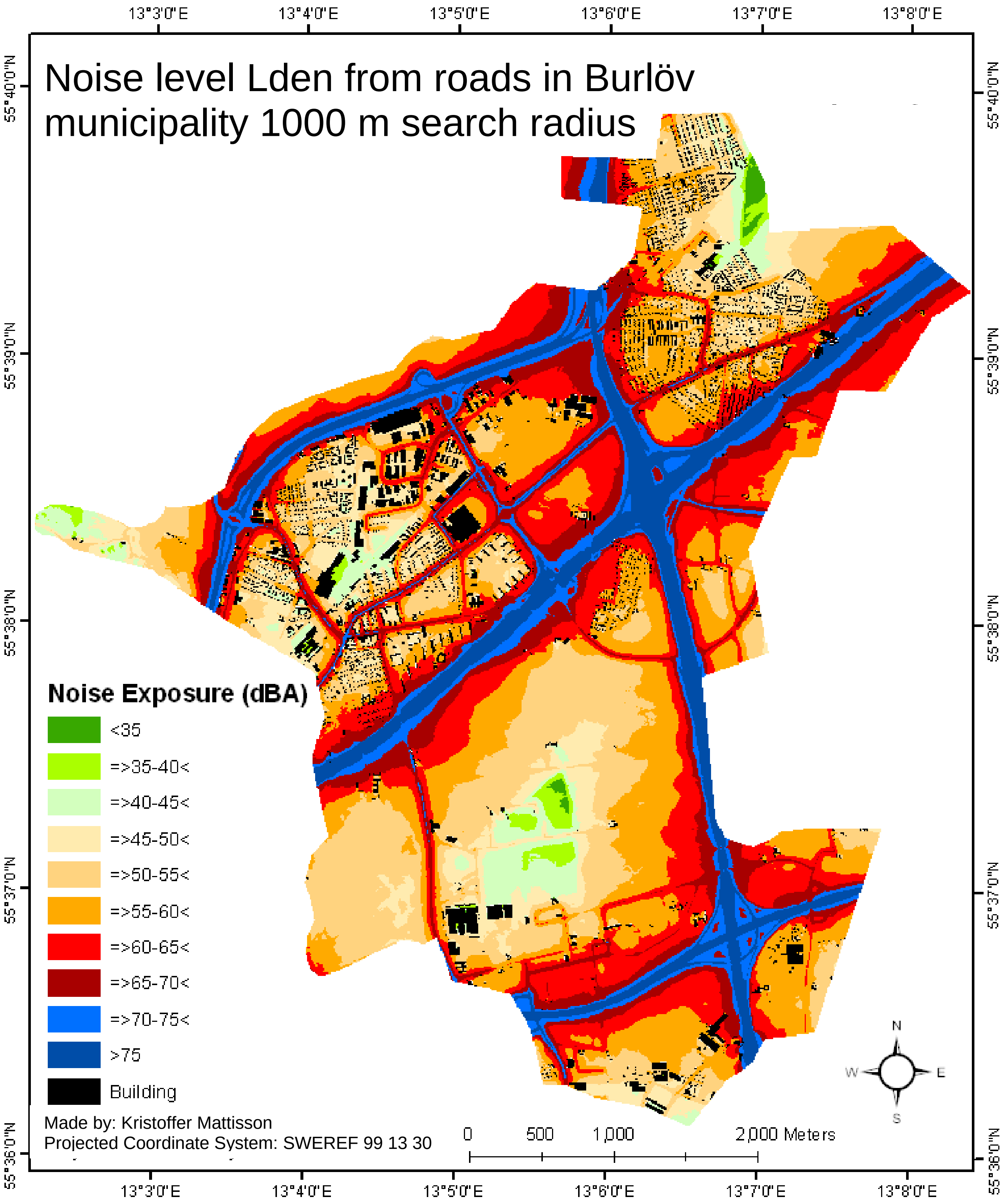


Figure H2: Area exposed to different levels of noise to the measure L_{den} at 4 m height in Burlöv municipality using 1000 m search radius. Noise has been calculated in a grid with 10 m between each calculation point. Road traffic noise – Nordic prediction method from 1996 implemented in the software SoundPLAN has been used to model the noise.

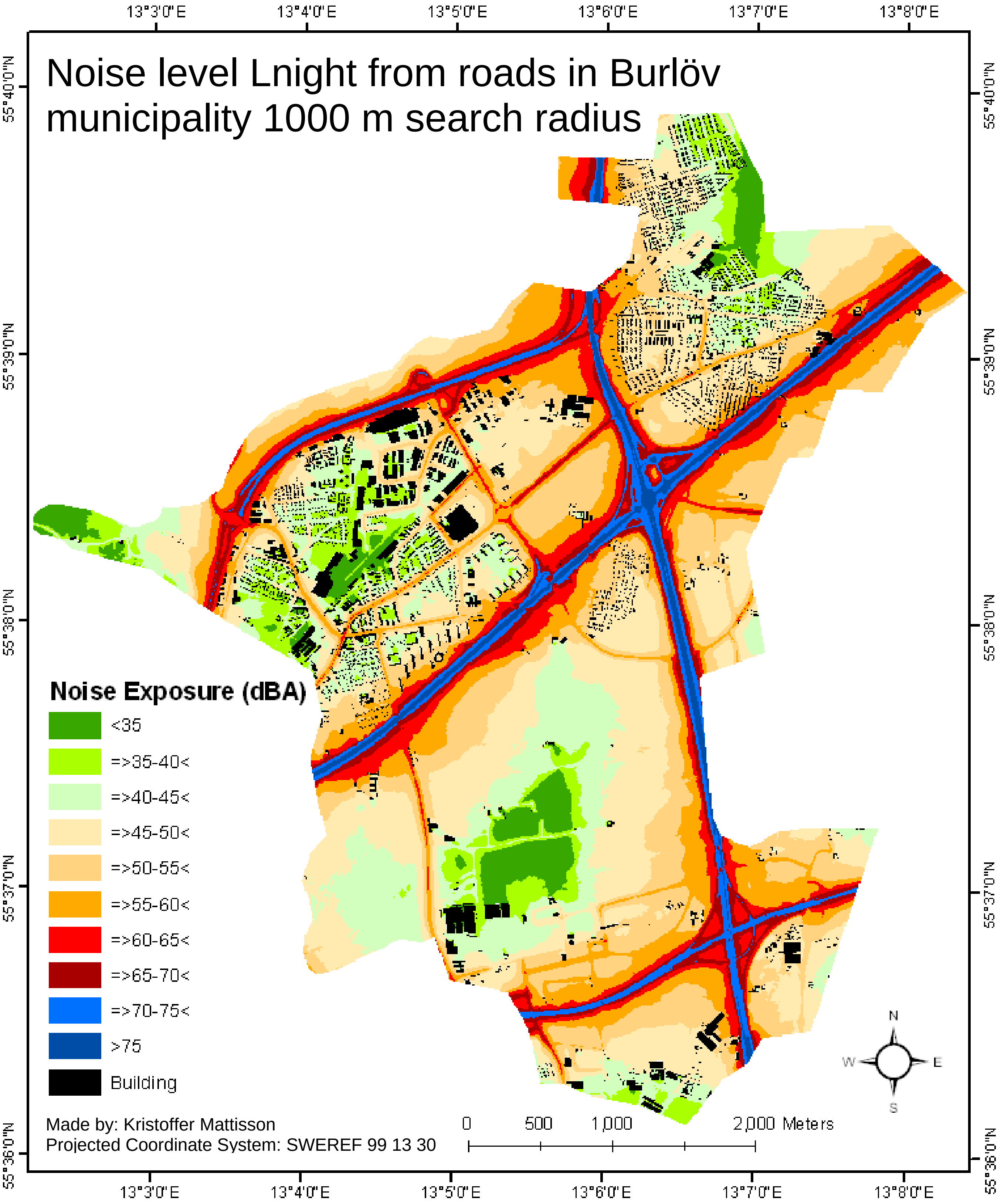


Figure H3: Area exposed to different levels of noise to the measure L_{night} at 4 m height in Burlöv municipality using 1000 m search radius. Noise has been calculated in a grid with 10 m between each calculation point. Road traffic noise – Nordic prediction method from 1996 implemented in the software SoundPLAN has been used to model the noise.

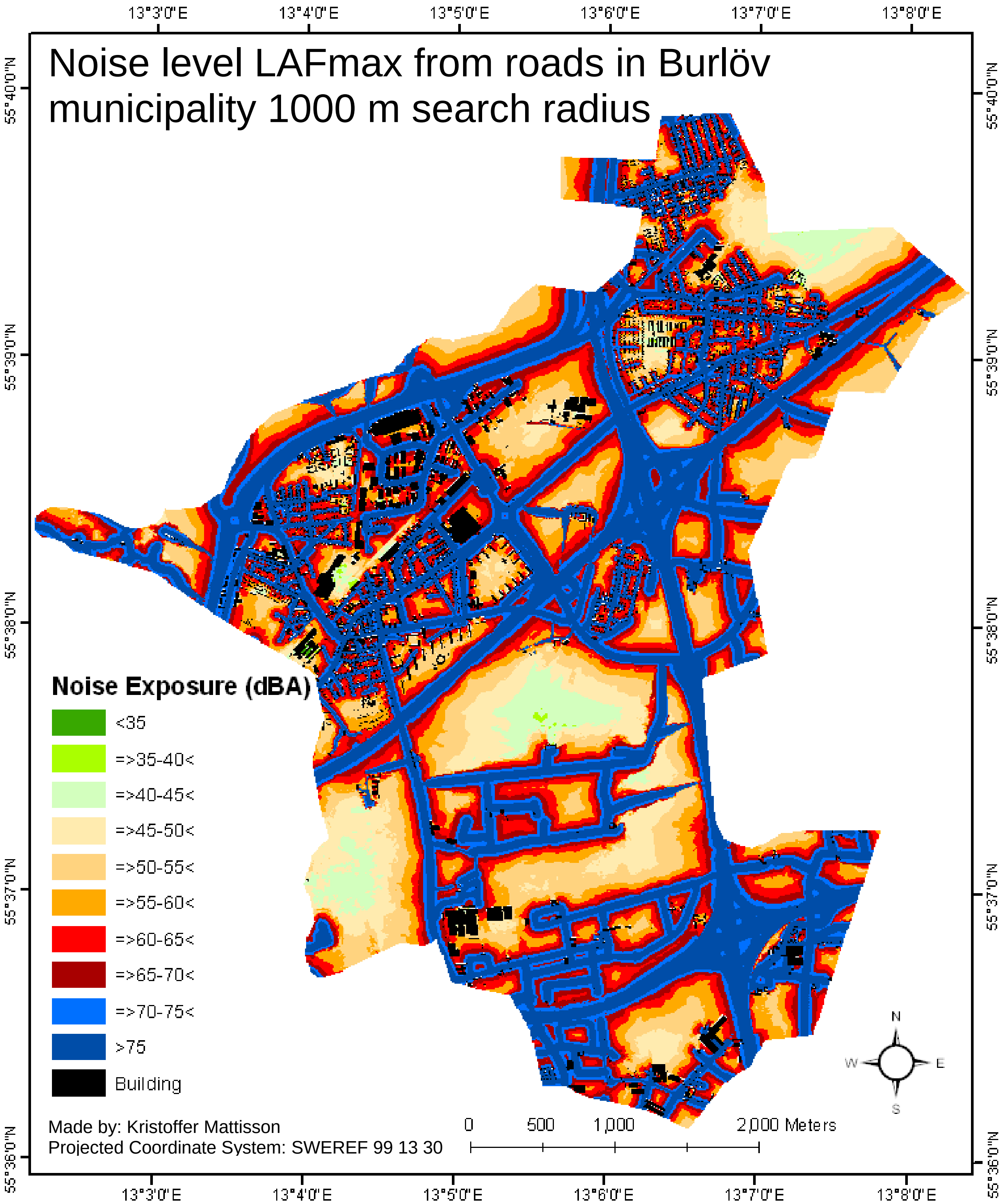


Figure H4: Area exposed to different levels of noise to the measure $L_{AF\,\max}$ at 4 m height in Burlöv municipality using 1000 m search radius. Noise has been calculated in a grid with 10 m between each calculation point. Road traffic noise – Nordic prediction method from 1996 implemented in the software SoundPLAN has been used to model the noise.

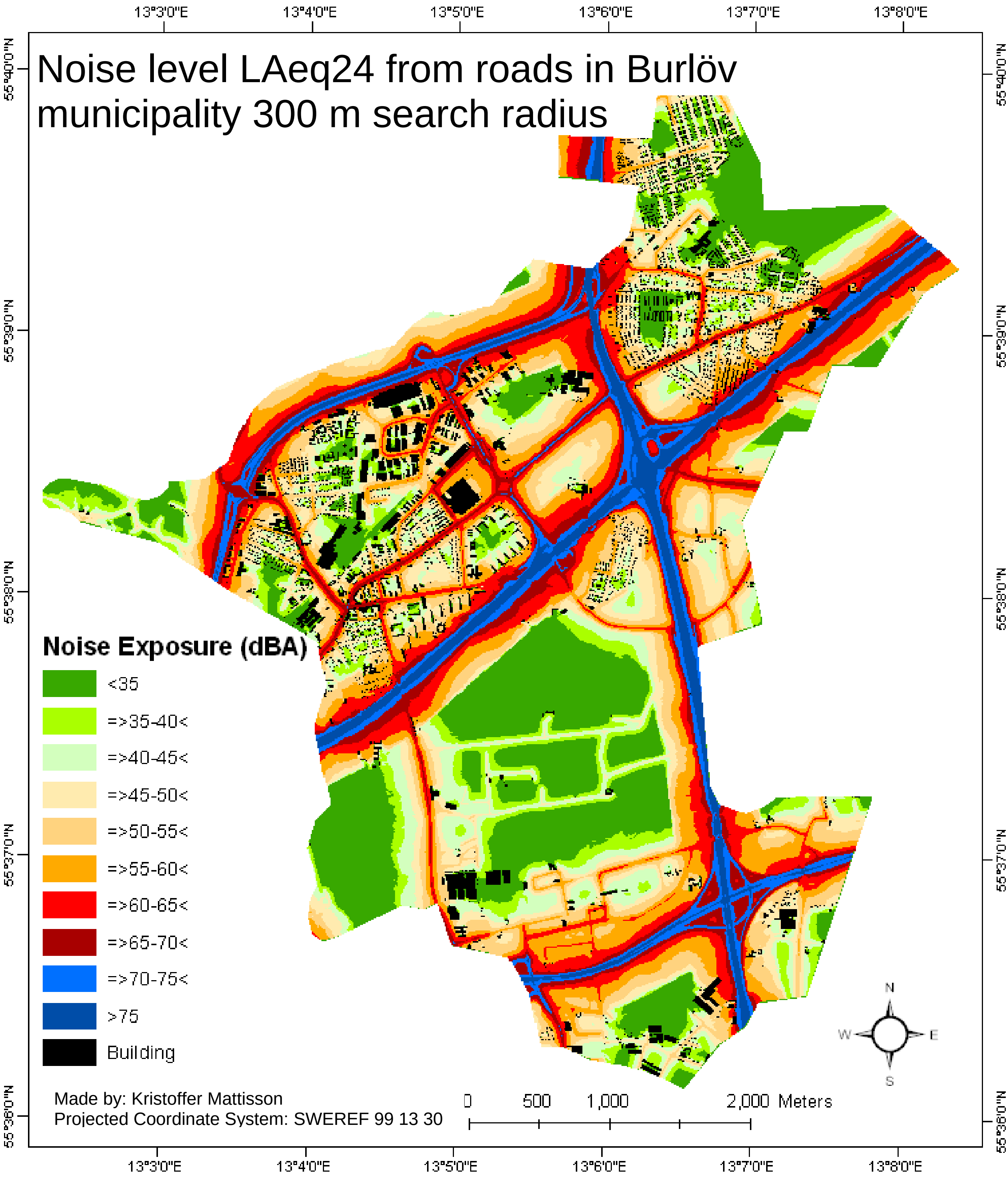


Figure H5: Area exposed to different levels of noise to the measure L_{Aeq24} at 4 m height in Burlöv municipality using 300 m search radius. Noise has been calculated in a grid with 10 m between each calculation point. Road traffic noise – Nordic prediction method from 1996 implemented in the software SoundPLAN has been used to model the noise.

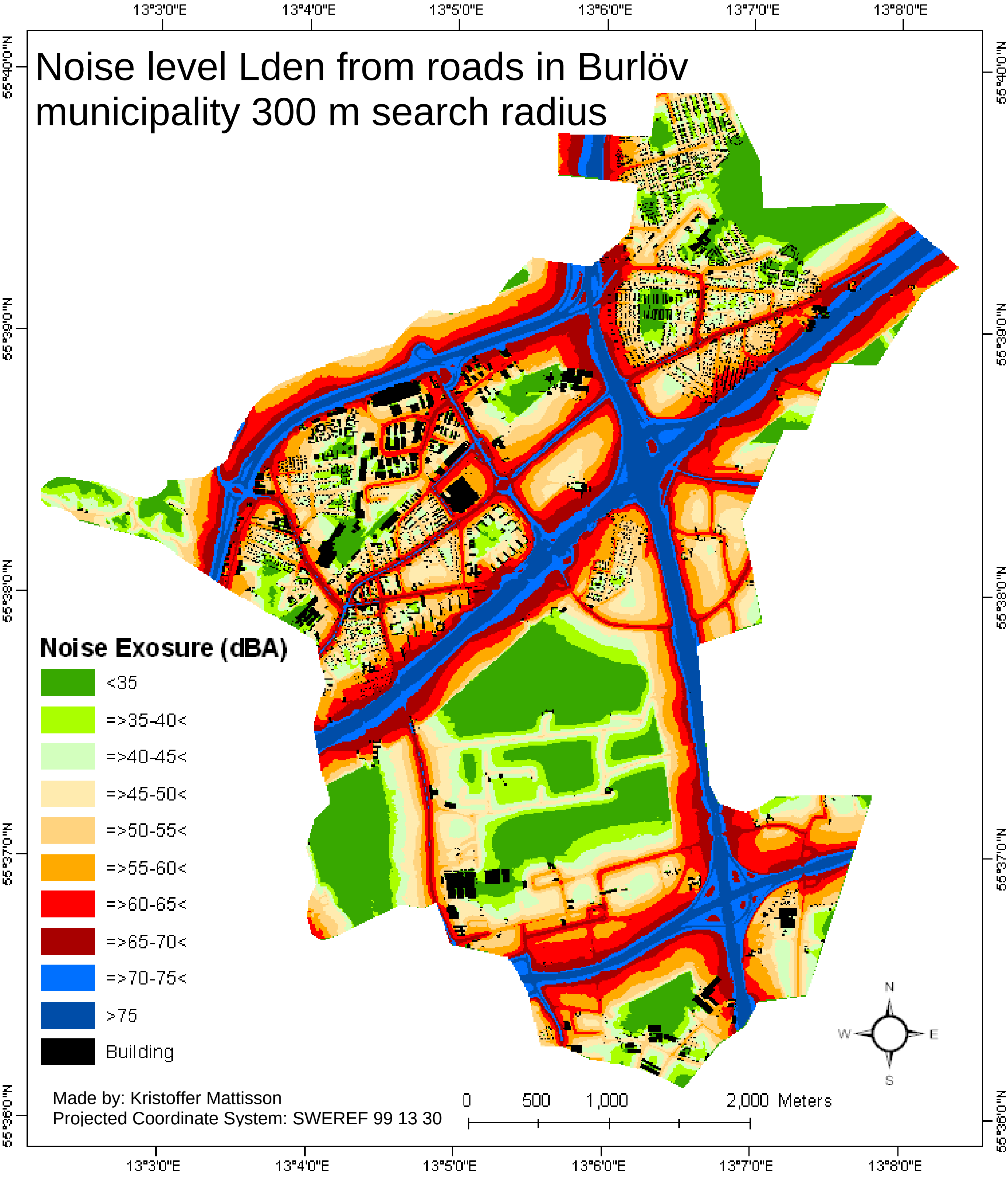


Figure H6: Area exposed to different levels of noise to the measure L_{den} at 4 m height in Burlöv municipality using 300 m search radius. Noise has been calculated in a grid with 10 m between each calculation point. Road traffic noise – Nordic prediction method from 1996 implemented in the software SoundPLAN has been used to model the noise.

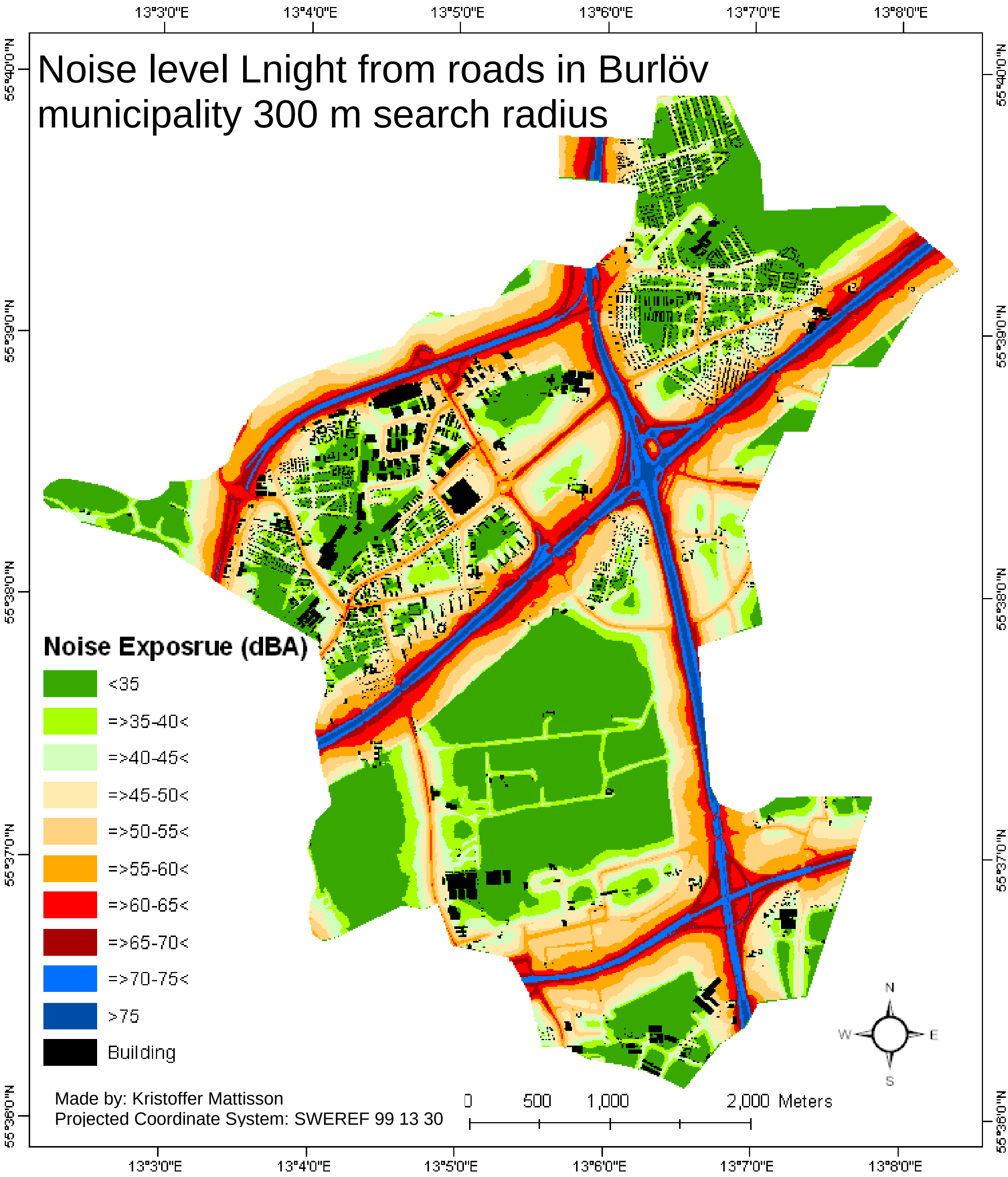


Figure H7: Area exposed to different levels of noise to the measure L_{night} at 4 m height in Burlöv municipality using 300 m search radius. Noise has been calculated in a grid with 10 m between each calculation point. Road traffic noise – Nordic prediction method from 1996 implemented in the software SoundPLAN has been used to model the noise.

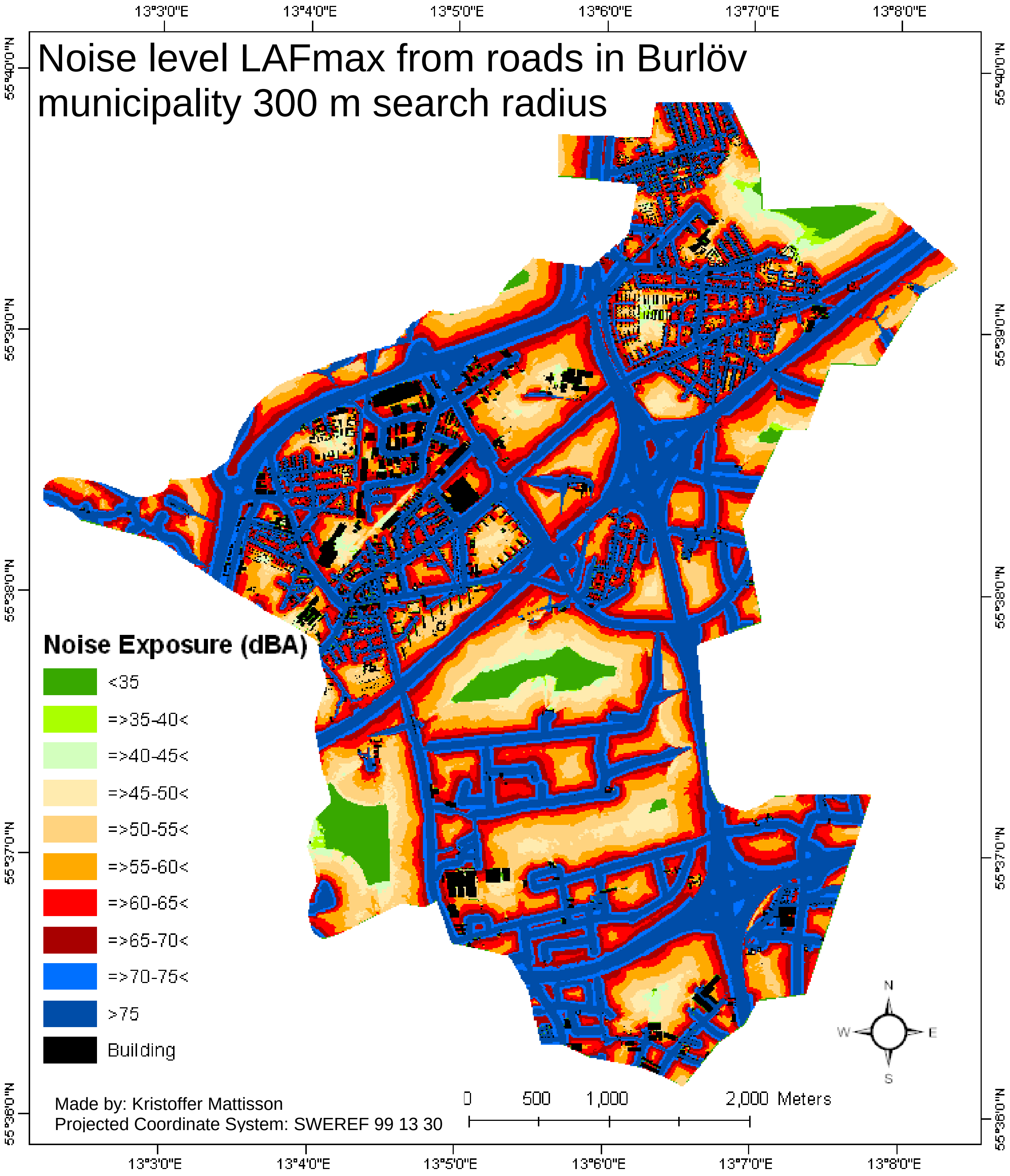


Figure H8: Area exposed to different levels of noise to the measure $L_{AF\max}$ at 4 m height in Burlöv municipality using 300 m search radius. Noise has been calculated in a grid with 10 m between each calculation point. Road traffic noise – Nordic prediction method from 1996 implemented in the software SoundPLAN has been used to model the noise.

Table H1: Area exposed to L_{Aeq24} using a 1000 m search radius

Exposure level dB(A)	Area (km2)	%
35<	0.15	0.8
=>35-40<	0.5	2.7
=>40-45<	1.02	5.5
=>45-50<	3.07	16.4
=>50-55<	4.45	23.8
=>55-60<	3.83	20.4
=>60-65<	2.54	13.6
=>65-70<	1.43	7.7
=>70-75<	0.93	5.0
=>75-80<	0.58	3.1
=>80-85<	0.23	1.2
>85	0	0.0
Summa:	**18.75**	**100.0**

Table H2: Area exposed to L_{den} using a 1000 m search radius

Exposure level dB(A)	Area (km2)	%
35<	0.06	0.3
=>35-40<	0.19	1.0
=>40-45<	0.63	3.4
=>45-50<	1.34	7.1
=>50-55<	3.71	19.8
=>55-60<	4.27	22.8
=>60-65<	3.65	19.4
=>65-70<	2.16	11.5
=>70-75<	1.22	6.5
=>75-80<	0.87	4.7
=>80-85<	0.5	2.7
>85	0.16	0.9
Summa:	**18.75**	**100.0**

Table H3: Area exposed to L_{night} using a 1000 m search radius

Exposure level dB(A)	Area (km2)	%
35<	0.69	3.7
=>35-40<	1.03	5.5
=>40-45<	2.63	14.0
=>45-50<	4.42	23.6
=>50-55<	3.8	20.3
=>55-60<	2.77	14.8
=>60-65<	1.42	7.5
=>65-70<	0.94	5.0
=>70-75<	0.69	3.7
=>75-80<	0.35	1.9
=>80-85<	0.01	0.0
>85	0	0.0
Summa:	**18.75**	**100.0**

Table H4: Area exposed to $L_{AF\max}$ using a 1000 m search radius

Exposure level dB(A)	Area (km2)	%
35<	0	0.0
=>35-40<	0.01	0.1
=>40-45<	0.54	2.9
=>45-50<	1.3	6.9
=>50-55<	2.1	11.2
=>55-60<	2.35	12.5
=>60-65<	2.41	12.9
=>65-70<	2.36	12.6
=>70-75<	2.32	12.4
=>75-80<	2.05	10.9
=>80-85<	1.27	6.8
>85	2.04	10.9
Summa:	**18.75**	**100.0**

Table H5: Area exposed to L_{Aeq24} using a 300 m search radius

Exposure level dB(A)	Area (km2)	%
35<	3.51	18.7
=>35-40<	1.32	7.0
=>40-45<	1.71	9.1
=>45-50<	2.2	11.7
=>50-55<	2.28	12.2
=>55-60<	2.61	13.9
=>60-65<	2.06	11.0
=>65-70<	1.34	7.1
=>70-75<	0.91	4.9
=>75-80<	0.57	3.0
=>80-85<	0.23	1.2
>85	0	0.0
Summa:	**18.75**	**100.0**

Table H6: Area exposed to L_{den} using a 300 m search radius

Exposure level dB(A)	Area (km2)	%
35<	2.8	14.9
=>35-40<	1.18	6.3
=>40-45<	1.44	7.7
=>45-50<	1.86	9.9
=>50-55<	2.16	11.5
=>55-60<	2.32	12.4
=>60-65<	2.51	13.4
=>65-70<	1.83	9.8
=>70-75<	1.15	6.1
=>75-80<	0.86	4.6
=>80-85<	0.49	2.6
>85	0.16	0.9
Summa:	**18.75**	**100.0**

Table H7: Area exposed to L_{night} using a 300 m search radius

Exposure level dB(A)	Area (km2)	%
35<	5.28	28.1
=>35-40<	1.83	9.8
=>40-45<	1.88	10.1
=>45-50<	2.07	11.0
=>50-55<	2.42	12.9
=>55-60<	2.05	10.9
=>60-65<	1.28	6.8
=>65-70<	0.92	4.9
=>70-75<	0.67	3.6
=>75-80<	0.34	1.8
=>80-85<	0.01	0.0
>85	0	0.0
Summa:	**18.75**	**100.0**

Table H8: Area exposed to $L_{AF\max}$ using a 300 m search radius

Exposure level dB(A)	Area (km2)	%
35<	0.55	2.9
=>35-40<	0.06	0.3
=>40-45<	0.2	1.1
=>45-50<	0.8	4.3
=>50-55<	1.9	10.1
=>55-60<	2.57	13.7
=>60-65<	2.57	13.7
=>65-70<	2.43	13.0
=>70-75<	2.33	12.4
=>75-80<	2.03	10.9
=>80-85<	1.26	6.7
>85	2.02	10.8
Summa:	**18.75**	**100.0**

Appendix I – Complement to the sensitivity analysis with comparison of four factors

Building Height	**Lden (dB)**	**Lnight (dB)**	**LAeq (dB)**	**Lmax (dB)**	**Run time**
Laser calculated height	43.6	34.9	40.2	52.3	7min 30 sec
All buildings 8 m height	37.8	29.7	34.7	46.0	6 min 22 sec

Figure I1: Comparison of using height of buildings calculated from the laser elevation and assigning all buildings the height of 8 m when modelling noise in Burlöv. The table show average noise exposure of the façades inside the study area for different noise measures. Italic text shows the reference run i.e. the same factors as in the main study.

Ground Absorption	**Lden (dB)**	**Lnight (dB)**	**LAeq (dB)**	**Lmax (dB)**	**Run time**
Soft ground	43.6	34.9	40.2	52.3	7min 30 sec
Hard ground	44.5	35.8	41.1	53.4	7 min 5 sec

Figure I2: Comparison of have all ground as soft or all ground as hard when modelling noise in Burlöv. The table show average noise exposure of the façades inside the study area for different noise measures. Italic text shows the reference run i.e. the same factors as in the main study.

Noise Wall	**Lden (dB)**	**Lnight (dB)**	**LAeq (dB)**	**Lmax (dB)**	**Run time**
No wall	43.6	34.9	40.2	52.3	7min 30 sec
2 m noise wall	42.8	34.0	39.4	52.1	7 min 17 sec

Figure I3: Comparison of including or excluding a noise wall when modelling noise in Burlöv. The table show average noise exposure of the façades inside the study area for different noise measures. Italic text shows the reference run i.e. the same factors as in the main study.

Search field	**Lden (dB)**	**Lnight (dB)**	**LAeq (dB)**	**Lmax (dB)**	**Run time**
360 degree	43.6	34.9	40.2	52.3	7min 30 sec
180 degree	41.7	32.8	38.3	52.3	5 min 7 sec

Figure I4: Comparison of searching for sources of noise in 360 or 180 degree search radius when modelling noise in Burlöv. The table show average noise exposure of the façades inside the study area for different noise measures. Italic text shows the reference run i.e. the same factors as in the main study.

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The reports are available at the Geo-Library, Department of Physical Geography, University of Lund, Sölvegatan 12, S-223 62 Lund, Sweden.
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